CHAPTER 3

Technical Issues In Planning Water Reuse Systems

This chapter considers technical issues associated with planning the beneficial reuse of reclaimed water derived from domestic wastewater facilities. These technical issues include the:

- Identification and characterization of potential demands for reclaimed water
- Identification and characterization of existing sources of reclaimed water to determine their potential for reuse
- Treatment requirements for producing a safe and reliable reclaimed water that is suitable for its intended applications
- Storage facilities required to balance seasonal fluctuations in supply with fluctuations in demand
- Supplemental facilities required to operate a water reuse system, such as conveyance and distribution networks, operational storage facilities, alternative supplies, and alternative disposal facilities
- Potential environmental impacts of implementing water reclamation
- Identification of knowledge, skills, and abilities necessary to operate and maintain the proposed system

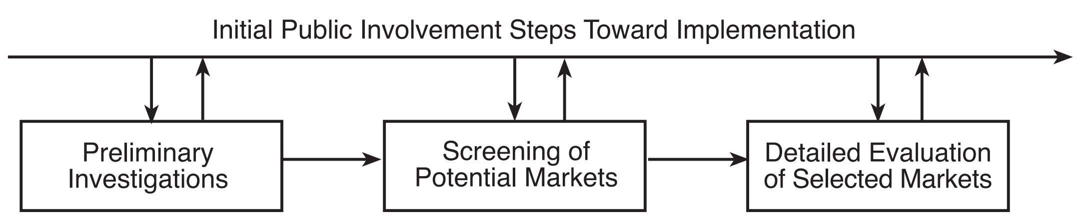
Technical issues of concern in specific reuse applications are discussed in Chapter 2, "Types of Reuse Applications."

3.1 Planning Approach

One goal of the *Guidelines for Water Reuse* is to outline a systematic approach to planning for reuse so that planners can make sound preliminary judgments about the local feasibility of reuse, taking into account the full range of key issues that must be addressed in implementing reclamation programs.

Figure 3-1 illustrates a 3-phase approach to reuse planning. This approach groups reuse planning activities into successive stages that include preliminary investigations, screening of potential markets, and detailed evaluation of selected markets. Each stage of activity builds on previous stages until enough information is available to develop a conceptual reuse plan and to begin negotiating the details of reuse with selected users. At each stage, from early planning through implementation, public involvement efforts play an important role. Public involvement efforts provide guidance to the planning process and outline steps that must be taken to support project implementation.

Figure 3-1. Phases of Reuse Program Planning



3.1.1 Preliminary Investigations

This is a fact-finding phase, meant to rough out physical, economic, and legal/institutional issues related to water reuse planning. The primary task is to locate all potential sources of effluent for reclamation and reuse and all potential markets for reclaimed water. It is also important to identify institutional constraints and enabling powers that might affect reuse. This phase should be approached with a broad view. Exploration of all possible options at this early planning stage will establish a practical context for the plan and also help to avoid creating dead-ends in the planning process.

Questions to be addressed in this phase include:

- What local sources of effluent might be suitable for reuse?
- What are the potential local markets for reclaimed water?
- What other nontraditional freshwater supplies are available for reuse?
- What are the present and projected reliability benefits of fresh water in the area?
- What are the present and projected user costs of fresh water in the area?
- What sources of funding might be available to support the reuse program?
- How would water reuse "integrate," or work in harmony with present uses of other water resources in the area?
- What public health considerations are associated with reuse, and how can these considerations be addressed?
- What are the potential environmental impacts of water reuse?
- What type of reuse system is likely to attract the public's interest and support?
- What existing or proposed laws and regulations affect reuse possibilities in the area?
- What local, state, or federal agencies must review and approve implementation of a reuse program?
- What are the legal liabilities of a purveyor or user of reclaimed water?

The major task of this phase involves conducting a preliminary market assessment to identify potential reclaimed water users. This calls for defining the water market through discussions with water wholesalers and retailers, and by identifying major water users in the market. The most common tools used to gather this type of information are telephone contacts and/or letters to potential reuse customers. Often, a follow-up phone contact is needed in order to determine what portion of total water use might be satisfied by reclaimed water, what quality of water is required for each type of use, and how the use of reclaimed water might affect the user's operations or discharge requirements.

This early planning stage is an ideal time to begin to develop or reinforce strong working relationships, among wastewater managers, water supply agencies, and potential reclaimed water users. These working relationships will help to develop solutions that best meet a particular community's needs.

Potential users will be concerned with the quality of reclaimed water and reliability of its delivery. They will also want to understand state and local regulations that apply to the use of reclaimed water. Potential customers will also want to know about constraints to using reclaimed water. They may have questions about connection costs or additional wastewater treatment costs that might affect their ability to use the product.

3.1.2 Screening of Potential Markets

The essence of this phase is to compare the unit costs of fresh water to a given market and the unit costs of reclaimed water to that same market. On the basis of information gathered in preliminary investigations, one or more "intuitive projects" may be developed that are clear possibilities, or that just "seem to make sense." For example, if a large water demand industry is located next to a wastewater treatment plant, there is a strong potential for reuse. The industry has a high demand for water, and costs to convey reclaimed water would be low. Typically, the cost-effectiveness of providing reclaimed water to a given customer is a function of the customer's potential demand versus the distance of the customer from the source of reclaimed water. In considering this approach, it should be noted that a concentration of smaller customers might represent a service area that would be as cost-effective to serve as a single large user. Once these anchor customers are identified, it is often beneficial to search for smaller customers located along the proposed path of the transmission system.

The value of reclaimed water – even to an "obvious" potential user will depend on the:

- Quality of water to be provided, as compared to the user's requirements
- Quantity of fresh water available and the ability to meet fluctuating demand
- Effects of laws that regulate reuse, and the attitudes of agencies responsible for enforcing applicable laws
- Present and projected future cost of fresh water to the user

These questions all involve detailed study, and it may not be cost-effective for public entities to apply the required analyses to every possible reuse scenario. A useful first step is to identify a wide range of candidate reuse systems that might be suitable in the area and to screen these alternatives. Then, only the most promising project candidates move forward with detailed evaluations.

In order to establish a comprehensive list of reuse possibilities, the following factors should be taken into account:

- Levels of treatment – if advanced wastewater treatment (AWT) is currently required prior to discharge of effluent, cost savings might be available if a market exists for secondary treated effluent.
- Project size – the scale of reuse can range from conveyance of reclaimed water to a single user up to the general distribution of reclaimed water for a variety of nonpotable uses.
- Conveyance network – different distribution routes will have different advantages, taking better advantage of existing rights-of-way, for example, or serving a greater number of users.

In addition to comparing the overall costs estimated for each alternative, several other criteria can be factored into the screening process. Technical feasibility may be used as one criterion, and the comparison of estimated unit costs of reclaimed water with unit costs of fresh water, as another. An even more complex screening process may include a comparison of weighted values for a variety of objective and subjective factors, such as:

- How much flexibility would each system offer for future expansion or change?
- How much fresh water use would be replaced by each system?
- How complicated would program implementation be, given the number of agencies that would be involved in each proposed system?
- To what degree would each system advance the "state-of-the-art" in reuse?
- What level of chemical or energy use would be associated with each system?
- How would each system impact land use in the area?

Review of user requirements could enable the list of potential markets to be reduced to a few selected markets for which reclaimed water could be of significant value. The Bay Area Regional Water Recycling Program (BARWRP) in San Francisco, California used a sophisticated screening and alternative analysis procedure. This included use of a regional GIS-based market assessment, a computer model to evaluate cost-effective methods for delivery, detailed evaluation criteria, and a spreadsheet-based evaluation decision methodology (Bailey *et al.,* 1998). The City of Tucson, Arizona, also used a GIS database to identify parcels such as golf courses, parks, and schools with a potential high demand for turf irrigation. In Cary, North Carolina, the parcel database was joined to the customer-billing database allowing large water users to be displayed on a GIS map. This process was a key element in identifying areas with high concentrations of dedicated irrigation meters on the potable water system (CDM, 1997). As part of an evaluation of water reclamation by the Clark County Sanitation District, Nevada, the alternatives analysis was extended beyond the traditional technical, financial, and regulatory considerations to include intangible criteria such as:

- Public acceptance including public education
- Sensitivity to neighbors
- Administrative agencies for the project
- Institutional arrangements to implement
- Impacts to existing developments as facilities are constructed

Source: Pai *et. al.,* 1996

3.1.3 Detailed Evaluation of Selected Markets

The evaluation steps contained in this phase represent the heart of the analyses necessary to shape a reuse program. At this point, a certain amount of useful data should be known including the present freshwater consumption and costs for selected potential users and a ranking of "most-likely" projects. In this phase, a more detailed look at conveyance routes and storage requirements for each selected system will help to refine preliminary cost estimates. Funding and benefit options can be compared, user costs developed, and a comparison made between the costs and benefits of fresh water versus reclaimed water for each selected system. The detailed evaluation will also look in more detail at the environmental, institutional, and social aspects of each project.

Questions that may need to be addressed as part of the detailed evaluation include:

- What are the specific water quality requirements of each user? What fluctuation can be tolerated?
- What is the daily and seasonal water use demand pattern for each potential user?
- Can fluctuations in demand best be met by pumping capacity or by using storage? Where would storage facilities best be located?
- If additional effluent treatment is required, who should own and operate the additional treatment facilities?
- What costs will the users in each system incur in connecting to the reclaimed water delivery system?
- Will industrial users in each system face increased treatment costs for their waste streams as a result of using reclaimed water? If so, is increased internal recycling likely, and how will this affect their water use?
- Will customers in the service area allow project costs to be spread over the entire service area?
- What interest do potential funding agencies have in supporting each type of reuse program being considered? What requirements would these agencies impose on a project eligible for funding?
- Will use of reclaimed water require agricultural users to make a change to their irrigation patterns or to provide better control of any irrigation discharges?
- What payback period is acceptable to users who must invest in additional facilities for onsite treatment, storage, or distribution of reclaimed water?
- What are the prospects of industrial source control measures in the area, and would institution of such measures reduce the additional treatment steps necessary to permit reuse?
- How "stable" are the potential users in each selected candidate reuse system? Are they likely to remain in their present locations? Are process changes being considered that might affect their ability to use reclaimed water?

Many of these questions can be answered only after further consultation with water supply agencies and prospective users. Both groups may seek more detailed information as well, including the preliminary findings made in the first 2 phases of effort. The City of Tampa set the following goals and objectives for their first residential reclaimed water project:

- Demonstrate customer demand for the water
- Demonstrate customer willingness to pay for the service
- Show that the project would pay for itself and not be subsidized by any utility customer not receiving reclaimed water
- Make subscription to the reclaimed water service voluntary

Source: Grosh *et. al.,* 2002

Detailed evaluations should lead to a preliminary assessment of technical feasibility and costs. Comparison among alternative reuse programs will be possible, as well as preliminary comparison between these programs and alternative water supplies, both existing and proposed. In this phase, economic comparisons, technical optimization steps, and environmental assessment activities leading to a conceptual plan for reuse might be accomplished by working in conjunction with appropriate consulting organizations.

3.2 Potential Uses of Reclaimed Water

Urban public water supplies are treated to satisfy the requirements for potable use. However, potable use (drinking, cooking, bathing, laundry, and dishwashing) represents only a fraction of the total daily residential use of treated potable water. The remainder may not require water of potable quality. In many cases, water used for nonpotable purposes, such as irrigation, may be drawn from the same ground or surface source as municipal supplies, creating an indirect demand on potable supplies. The *Guidelines* examine opportunities for substituting reclaimed water for potable water supplies where potable water quality is not required. Specific reuse opportunities include:

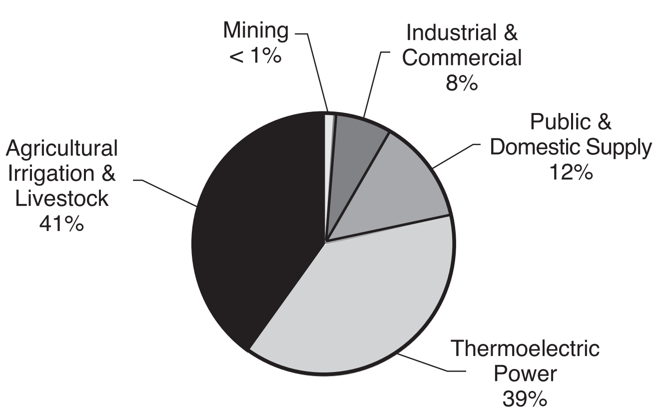
- Urban
- Industrial
- Agricultural
- Environmental and Recreational
- Groundwater Recharge
- Augmentation of Potable Supplies

The technical issues associated with the implementation of each of these reuse alternatives are discussed in detail in Chapter 2. The use of reclaimed water to provide both direct and indirect augmentation of potable supplies is also presented in Chapter 2.

3.2.1 National Water Use

Figure 3-2 presents the national pattern of water use in the U.S. according to the U.S. Geological Survey (Solley *et al.,* 1998). Total water use in 1995 was 402,000 mgd (152×10^7 m^3/d) with 341,000 mgd (129×10^7 m^3/d) being fresh water and 61,000 mgd (23×10^7 m^3/d) saline water. The largest freshwater demands were associated with agricultural irrigation/livestock and thermoelectric power, representing 41 and 39 percent, respectively, of the total freshwater use in the United States. Public and domestic water uses constitute 12 percent of the total demand.

Figure 3-2. 1995 U.S. Fresh Water Demands by Major Uses



Source: Solley *et. al*., 1998

The remainder of the water use categories are mining and industrial/commercial with 8 percent of the demand. The 2 largest water use categories, thermoelectric power and agricultural irrigation, account for 80 percent of the total water use. These water uses present a great potential for supplementing with reclaimed water.

Figure 3-3 provides a flow chart illustrating the source, use, and disposition of fresh water in the U.S. Of the 341,000 mgd (129×10^7 m^3/d) of fresh water used in the U.S., only 29 percent is consumptively used and 71 percent is return flow. This amounts to a total of 241,000 mgd (91×10^7 m^3/d), of which 14 percent originates from domestic and commercial water use. Domestic wastewater comprises a large portion of this number.

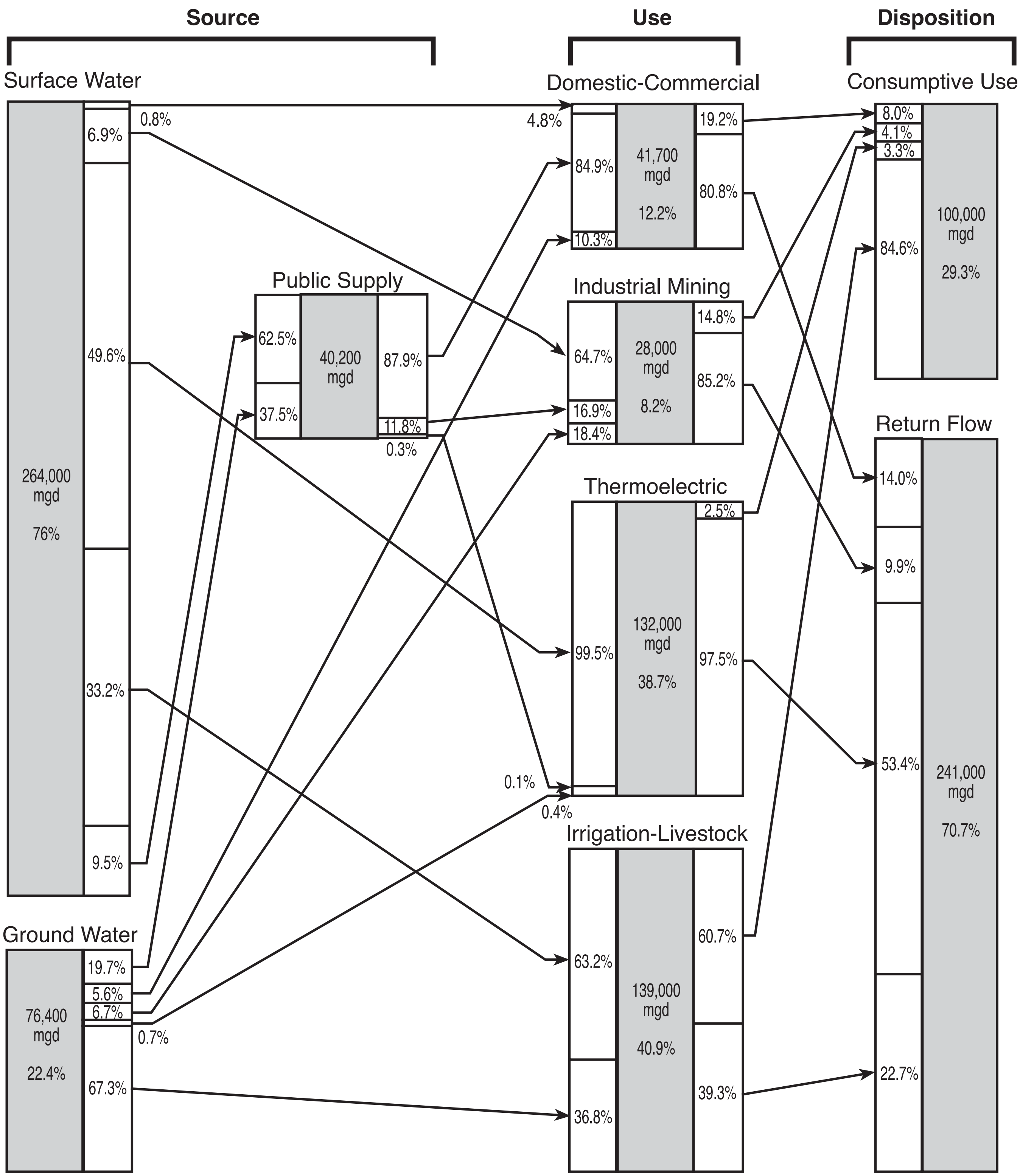
Figure 3-4 shows estimated wastewater effluent produced daily in each state, representing the total potential reclaimed water supply from existing wastewater treatment facilities. **Figure 3-5** shows the estimated water demands by state in the United States. Estimated water demands are equal to the total fresh and saline withdrawals for all water-use categories (public supply, domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power). Areas where high water demand exists might benefit by augmenting existing water supplies with reclaimed water. Municipalities in coastal and arid states, where water demands are high and freshwater supplies are limited, appear to have a reasonable supply of wastewater effluent that could, through proper treatment and reuse, greatly extend their water supplies.

Arid regions of the U.S. (such as the southwest) are candidates for wastewater reclamation, and significant reclamation projects are underway throughout this region. Yet, arid regions are not the only viable candidates for water reuse. Local opportunities may exist for a given municipality to benefit from reuse by extending local water supplies and/or reducing or eliminating surface water discharge. For example, the City of Atlanta, Georgia, located in the relatively water-rich southeast, has experienced water restrictions as a result of recurrent droughts. In south Florida, subtropical conditions and almost 55 inches (140 cm) per year of rainfall suggest an abundance of water; however, landscaping practices and regional hydrogeology combine to result in frequent water shortages and restrictions on water use. Thus, opportunities for water reclamation and reuse must be examined on a local level to judge their value and feasibility.

3.2.2 Potential Reclaimed Water Demands

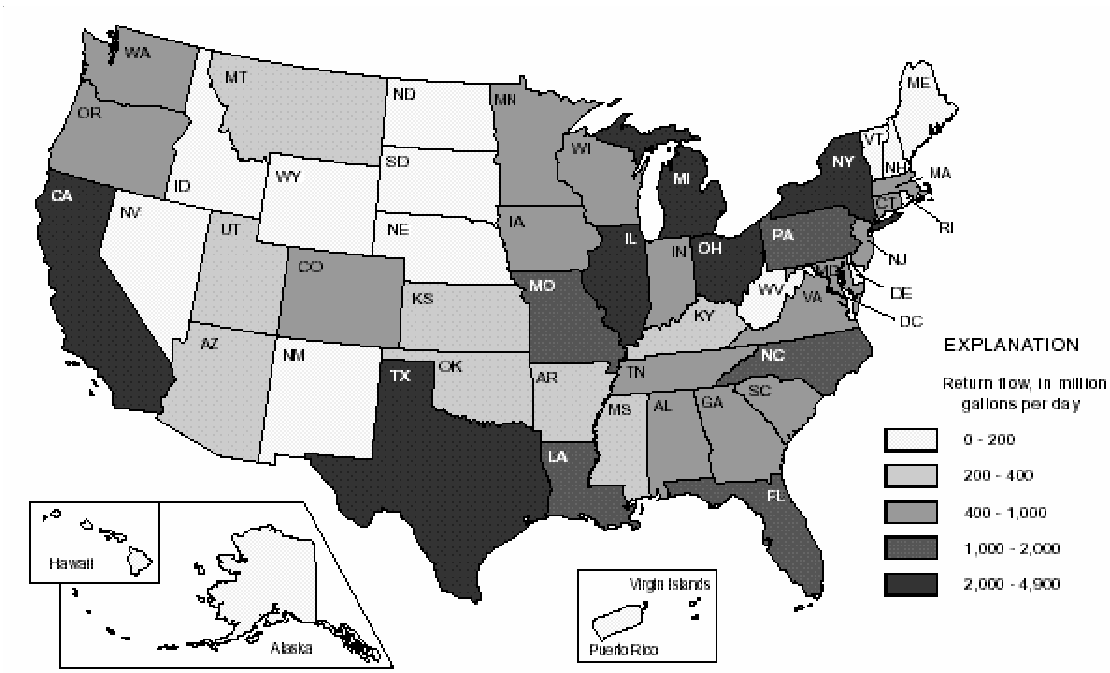
Residential water demand can further be categorized as indoor use, which includes toilet flushing, cooking, laundry, bathing, dishwashing, and drinking; or outdoor use,

Figure 3-3. **Fresh Water Source, Use and Disposition**



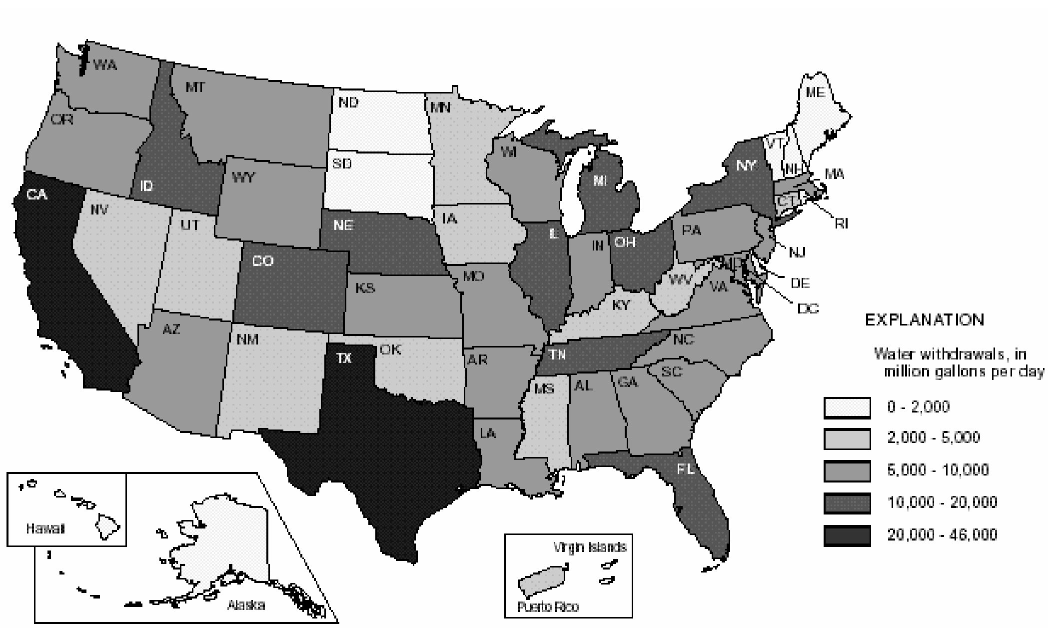
Source: Solley *et. al.*, 1998

Figure 3-4. Wastewater Treatment Return Flow by State, 1995



Source: Solley *et al.*, 1998

Figure 3-5. Total Withdrawals



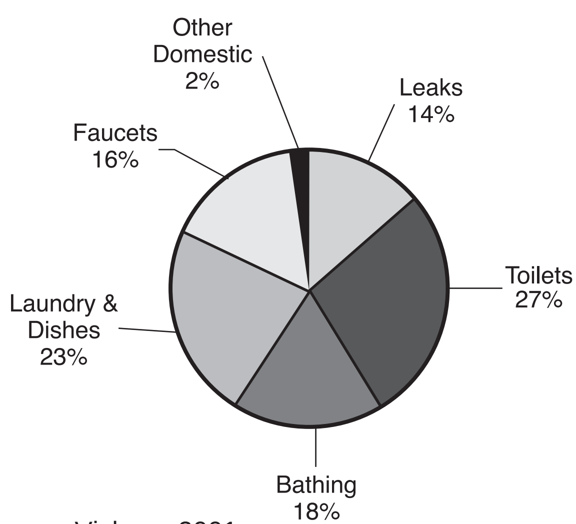
Source: Solley *et al.*, 1998

which consists primarily of landscape irrigation. Outdoor use accounts for approximately 31 percent of the residential demand, while indoor use represents approximately 69 percent (Vickers, 2001). **Figure 3-6** presents the average residential indoor water use by category. It should be noted that these are national averages, and few residential households will actually match these figures. Inside the home, the largest use of water is toilet flushing (almost 30 percent). The potable use (cooking, drinking, bathing, laundry, and dishwashing) represents about 60 percent of the indoor water use or about 40 percent of the total residential (outdoor and indoor) demand. Reclaimed water could be used for all nonpotable uses (toilet flushing and outdoor use), which are approximately 50 percent of the total residential water demand. Leaks are neglected in these calculations.

Approximately 38 billion gallons of water is produced daily in the U.S. for domestic and public use. On average, a typical American household consumes at least 50 percent of their water through lawn irrigation. The U.S. has a daily requirement of 40 billion gallons (152 million m^3) a day of fresh water for general public use. This requirement does not include the 300 billion gallons (1,135 million m^3) used for agricultural and commercial purposes. For example, a dairy cow must consume 4 gallons (15 l) of water to produce 1 gallon (4 l) of milk, and it takes 300 million gallons (1.1 million m^3) of water to produce a 1-day supply of U.S. newsprint (American Water Works Association Website, 2003).

The need for irrigation is highly seasonal. In the North where turf goes dormant, irrigation needs will be zero in the winter months. However, irrigation demand may represent a significant portion of the total potable water demand in the summer months. In coastal South Carolina, winter irrigation use is estimated to be less than 10 percent of the total potable demand. This increases to over 30 percent in the months of June and July. In Denver, during July and August when temperatures exceed 90 °F (32 °C), approximately 80 percent of all potable water may be used for irrigation. Given the seasonal nature of urban irrigation, eliminating this demand from the potable system through reuse will result in a net annual reduction in potable demands and, more importantly, may also significantly reduce peak-month potable water demands.

Figure 3-6. Average Indoor Water Usage (Total = 69.3 gpcd)



Source: Vickers, 2001

It is not surprising then that landscape irrigation currently accounts for the largest urban use of reclaimed water in the U.S. This is particularly true of urban areas with substantial residential areas and a complete mix of landscaped areas ranging from golf courses to office parks to shopping malls. Urban areas also have schools, parks, and recreational facilities, which require regular irrigation. Within Florida, for example, studies of potable water consumption have shown that 50 to 70 percent of all potable water produced is used for outside purposes, principally irrigation.

The potential irrigation demand for reclaimed water generated by a particular urban area can be estimated from an inventory of the total irrigable acreage to be served by the reuse system and the estimated weekly irrigation rates, determined by factors such as local soil characteristics, climatic conditions, and type of landscaping. In some states, recommended weekly irrigation rates are available from water management agencies, county or state agricultural agents, and irrigation specialists. Reclaimed water demand estimates should also take into account any other proposed uses for reclaimed water within the proposed service area, such as industrial cooling and process water, decorative fountains, and other aesthetic water features.

Agricultural irrigation represents 40 percent of total water demand nationwide and presents another significant opportunity for water reuse, particularly in areas where agricultural sites are near urban areas and can easily be integrated with urban reuse applications. Such is the case in Orange County, California, where the Irvine Ranch Water District provides reclaimed water to irrigate urban landscape and mixed agricultural lands (orchards and vegetable row crops). As agricultural land use is displaced by residential development in this growing urban area, the District has the flexibility to convert its reclaimed water service to urban irrigation.

In Manatee County, Florida, agricultural irrigation is a significant component of a county-wide water reuse program. During 2002, the County's 3 water reclamation facilities, with a total treatment capacity of 34.4 mgd (1,500 l/s), provided about 10.2 mgd (446 l/s) of reclaimed water. This water was used to irrigate golf courses, parks, schools, residential subdivisions, a 1,500-acre (600-hectare) gladioli farm, and about 6,000 acres (2,400 hectares) of mixed agricultural lands (citrus, ridge and furrow crops, sod farms, and pasture). The original 20-year reuse agreements with the agricultural users are being extended for 10 years, ensuring a long-term commitment to reclaimed water with a significant water conservation benefit. The urban reuse system has the potential to grow as development grows. Manatee County has more than 385 acres (154 hectares) of lake storage (1,235 million gallons or 47 x 10^5 m^3 of volume) and 2 reclaimed water aquifer storage and recovery (ASR) projects.

A detailed inspection of existing or proposed water use is essential for planning any water reuse system. This information is often available through municipal billing records or water use monitoring data that is maintained to meet the requirements of local or regional water management agencies. In other cases, predictive equations may be required to adequately describe water demands. Water needs for various reuse alternatives are explored further in Chapter 2. In addition to expected nonpotable uses for reclaimed water, a review of literature shows consideration and implementation of reuse projects for a wide variety of demands including toilet flushing, commercial car washing, secondary and primary sources of fire protection, textile mills to maintain water features, cement manufacturing, and make-up water for commercial air conditioners. By identifying and serving a variety of water uses with reclaimed water, the utilization of reclaimed water facilities can be increased, thereby increasing the cost effectiveness of the system while at the same time increasing the volume of potable water conserved.

3.2.3 Reuse and Water Conservation

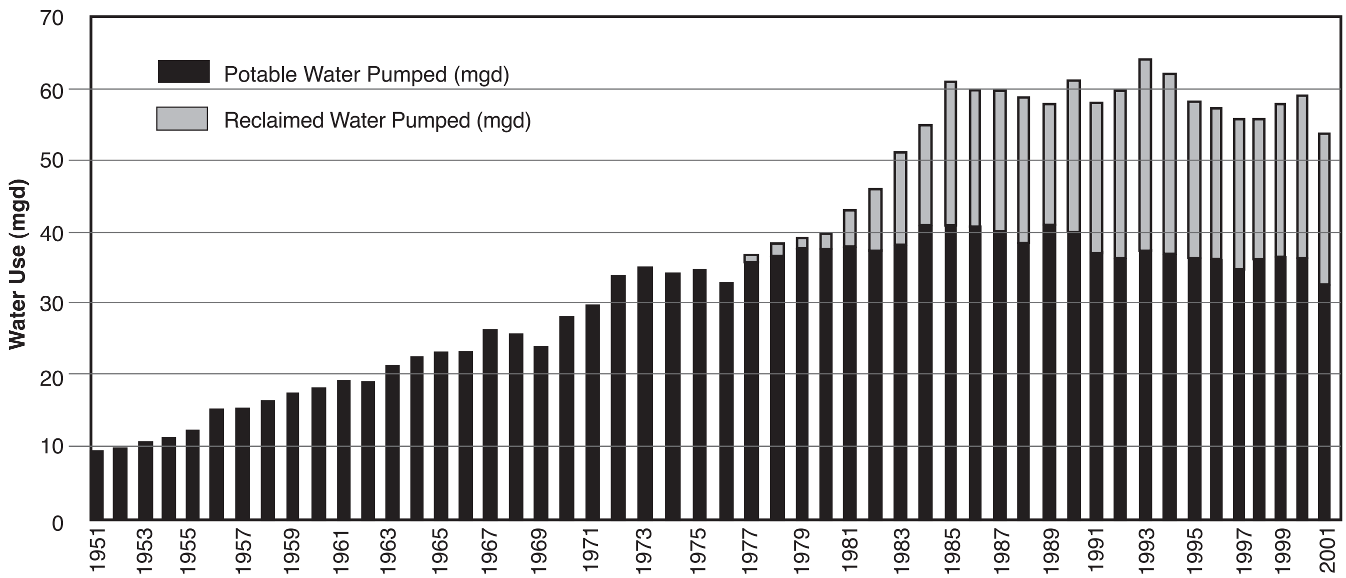
The need to conserve the potable water supply is an important part of urban and regional planning. For example, the Metropolitan Water District of Southern California predicted in 1990 that by the year 2010 water demands would exceed reliable supplies by approximately 326 billion gallons (1,200 x 10^9 m^3) annually (Adams, 1990). To help conserve the potable water supplies, the Metropolitan Water District developed a multi-faceted program that includes conservation incentives, rebate programs, groundwater storage, water exchange agreements, reservoir construction, and reclaimed water projects. Urban reuse of reclaimed water is an essential element of the program. In 2001, approximately 62 billion gallons (330 x 10^6 m^3) of reclaimed water were used in the District's service area for groundwater recharge, landscape irrigation, agricultural, commercial, and industrial purposes. It is estimated that more than 195 billion gallons (740 x 10^6 m^3) of reclaimed water will be reused by 2010. Due to long-term conservation programs, additional supply agreements, and an increase in the reclaimed water supply the District expects to meet the area's water needs for the next ten years even during times of critical drought (Metropolitan, 2002).

Perhaps the greatest benefit of urban reuse systems is their contribution to delaying or eliminating the need to expand potable water supply and treatment facilities. The City of St. Petersburg, Florida, has experienced about a 10 percent population growth since 1976 without any significant increase in potable water demand because of its urban reuse program. Prior to the start-up of its urban reuse system, the average residential water demand in a study area in St. Petersburg was 435 gallons per day (1,650 l/d). After reclaimed water was made available, the potable water demand was reduced to 220 gallons per day (830 l/d) (Johnson and Parnell, 1987). **Figure 3-7** highlights the City of St. Petersburg's estimated potable water savings since implementing an urban reuse program.

In 2001, Florida embarked on the *Water Conservation Initiative* (FDEP, 2002) – a program designed to promote water conservation in an effort to ensure water availability for the future. Recognizing the conservation and recharge potential of water reuse, a Water Reuse Work Group was convened to address the effective and efficient use of reclaimed water as a component in overall strategies to ensure water availability. The Water Reuse Work Group published its initial report in 2001 (FDEP, 2001) and published a more detailed strategy report in 2003 (FDEP, 2003). The final reuse strategy report includes 16 major strategies designed to ensure efficient and effective water reuse. Of particular note are strategies that encourage the use of reclaimed water meters and volume-based rates, in addition to encouraging groundwater recharge and indirect potable reuse.

Currently, approximately 20 percent of all water supplied by the Irvine Ranch Water District in southern California is reclaimed water. Total water demand is expected to reach 69 mgd (3,024 l/s) in Irvine by 2010. At that time Irvine expects to be able to provide service to meet approximately 26 mgd (1,139 l/s) of this demand with reclaimed water (Irvine Ranch Water District, 2002). An aggressive urban reuse program in Altamonte Springs, Florida is credited with a 30 percent reduction in potable water demands (Forest *et al.,* 1998).

Figure 3-7. Potable and Reclaimed Water Usage in St. Petersburg, Florida



3.3 Sources of Reclaimed Water

Under the broad definition of water reclamation and reuse, sources of reclaimed water may range from industrial process waters to the tail waters of agricultural irrigation systems. For the purposes of these guidelines, however, the sources of reclaimed water are limited to the effluent generated by domestic wastewater treatment facilities (WWTFs).

Treated municipal wastewater represents a significant potential source of reclaimed water for beneficial reuse. As a result of the Federal Water Pollution Control Act Amendments of 1972, the Clean Water Act of 1977 and its subsequent amendments, centralized wastewater treatment has become commonplace in urban areas of the U.S. In developed countries, approximately 73 percent of the population is served by wastewater collection and treatment facilities. Yet only 35 percent of the population of developing countries is served by wastewater collection. Within the U.S., the population generates an estimated 41 billion gallons per day (1.8 x 106 l/s) of potential reclaimed water (Solley *et al*., 1998). As the world population continues to shift from rural to urban, the number of centralized wastewater collection and treatment systems will also increase, creating significant opportunities to implement water reuse systems to augment water supplies and, in many cases, improve the quality of surface waters.

3.3.1 Locating the Sources

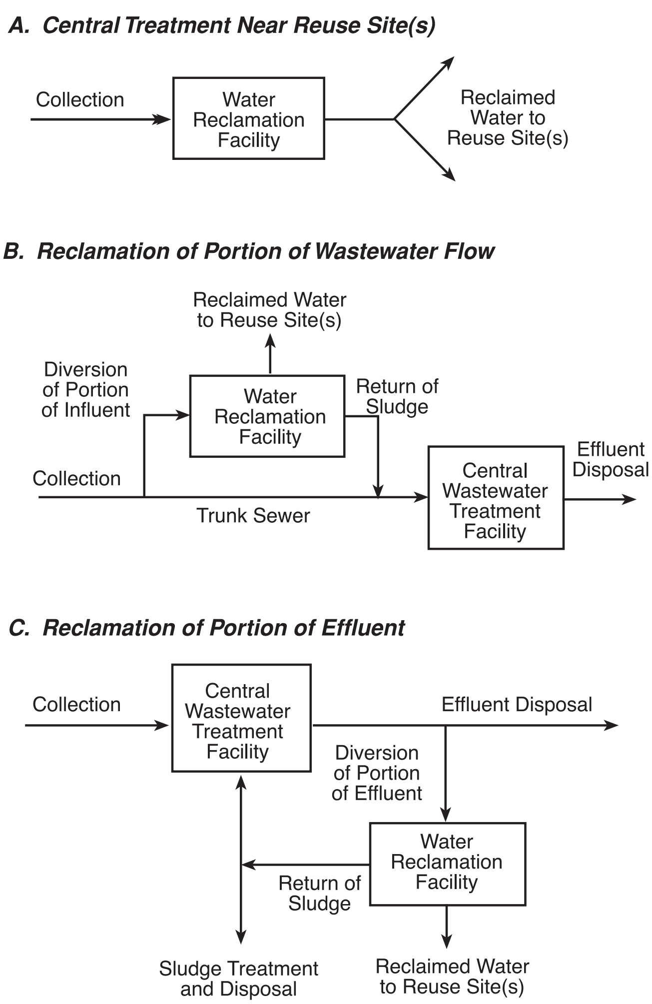
In areas of growth and new development, completely new collection, treatment, and distribution systems may be designed from the outset with water reclamation and reuse in mind. In most cases, however, existing facilities will be incorporated into the water reuse system. In areas where centralized treatment is already provided, existing WWTFs are potential sources of reclaimed water.

In the preliminary planning of a water reuse system incorporating existing facilities, the following information is needed for the initial evaluation:

- Residential areas and their principal sewers
- Industrial areas and their principal sewers
- Wastewater treatment facilities
- Areas with combined sewers
- Existing effluent disposal facilities
- Areas and types of projected development
- Locations of potential reclaimed water users

For minimizing capital costs, the WWTFs ideally should be located near the major users of the reclaimed water. However, in adapting an existing system for water reuse, other options are available. For example, if a trunk sewer bearing flows to a WWTF passes through an area of significant potential reuse, a portion of the flows can be diverted to a new "satellite" reclamation facility to serve that area. The sludge produced in the satellite reclamation facility can be returned to the sewer for handling at the WWTF. By this method, odor problems may be reduced or eliminated at the satellite reclamation facility. However, the effects of this practice can be deleterious to both sewers and downstream treatment facilities. Alternatively, an effluent outfall passing through a potential reuse area could be tapped for some or all of the effluent, and additional treatment could be provided, if necessary, to meet reclaimed water quality standards. These alternative configurations are illustrated in **Figure 3-8.**

Figure 3-8. Three Configuration Alternatives for Water Reuse Systems



3.3.2 Characterizing the Sources

Existing sources must be characterized to roughly establish the wastewater effluent's suitability for reclamation and reuse. To compare the quality and quantity of available reclaimed water with the requirements of potential users, information about the operation and performance of the existing WWTF and related facilities must be examined. Important factors to consider in this preliminary stage of reuse planning are:

- Level of treatment (e.g., primary, secondary, advanced) and specific treatment processes (e.g., ponds, activated sludge, filtration, disinfection, nutrient removal, disinfection)
- Effluent water quality
- Effluent quantity (use of historical data to determine daily and season at average, maximum, and minimum flows)
- Industrial wastewater contributions to flow
- System reliability
- Supplemental facilities (e.g., storage, pumping, transmission)

3.3.2.1 Level of Treatment and Processes

Meeting all applicable treatment requirements for the production of safe, reliable reclaimed water is one of the keys to operating any water reuse system. Thus careful analysis of applicable state and local requirements and provision of all necessary process elements are critical in designing a reuse system. Because of differing environmental conditions from region to region across the country, and since different end uses of the reclaimed water require different levels of treatment, a universal quality standard for reclaimed water does not exist. In the past, the main objective of treatment for reclaimed water was secondary treatment and disinfection. As wastewater effluent is considered a source for more and more uses, such as industrial process water or even potable supply water, the treatment focus has expanded beyond secondary treatment and disinfection to include treatment for other containments such as metals, dissolved solids, and emerging contaminants (such as pharmaceutical residue and endocrine disruptors). However, at this early planning stage, only a preliminary assessment of the compatibility of the secondary effluent quality and treatment facilities with potential reuse applications is needed. A detailed discussion of treatment requirements for water reuse applications is provided in Section 3.4.

Knowledge of the chemical constituents in the effluent, the level of treatment, and the treatment processes provided is important in evaluating the WWTF's suitability as a water reclamation facility and determining possible reuse applications. An existing plant providing at least secondary treatment, while not originally designed for water reclamation and reuse, can be upgraded by modifying existing processes or adding new unit processes to the existing treatment train to supply reclaimed water for most uses. For example, with the addition of chemicals, filters, and other facilities to ensure reliable disinfection, most secondary effluents can be enhanced to provide a source of reclaimed water suitable for unrestricted urban reuse. However, in some parts of the U.S., the effluent from a secondary treatment system may contain compounds of concern. Such effluent may not be used because it could result in water quality problems. In these cases, treatment processes must be selected to reduce these compounds before they are released. This can create additional disposal issues as well. A typical example would be the presence of elevated TDS levels within the effluent, resulting in problems where the reclaimed water is used for irrigation (Sheikh *et al.*, 1997; Dacko, 1997; Johnson, 1998).

In some cases, existing processes necessary for effluent disposal practices may no longer be required for water reuse. For example, an advanced wastewater treatment plant designed to remove nitrogen and/or phosphorus would not be needed for agricultural or urban irrigation, since the nutrients in the reclaimed water are beneficial to plant growth.

In addition to the unit processes required to produce a suitable quality of reclaimed water, the impact of any return streams (e.g., filter backwash, RO concentrate return, etc.) to the WWTF's liquid and solids handling processes should be considered.

3.3.2.2 Reclaimed Water Quality

Effluent water quality sampling and analysis are required as a condition of WWTF discharge permits. The specific parameters tested are those required for preserving the water quality of the receiving water body, (*e.g.,* biochemical oxygen demand, suspended solids, coliforms or other indicators, nutrients, and sometimes toxic organics and metals). This information is useful in the preliminary evaluation of a wastewater utility as a potential source of reclaimed water. For example, as noted earlier, the nitrogen and phosphorus in reclaimed water represents an advantage for certain irrigation applications. For industrial reuse, however, nutrients may encourage biological growths that could cause fouling. Where the latter uses are a small fraction of the total use, the customer may be obliged to remove the nutrients or blend reclaimed water with other water sources. The decision is based on case-by-case assessments.

In some cases, the water quality data needed to assess the suitability of a given source are not included in the WWTF's existing monitoring requirements and will have to be gathered specifically for the reuse evaluation. Coastal cities may experience saltwater infiltration into their sewer system, resulting in elevated chloride concentrations in the effluent or reclaimed water. Chloride levels are of concern in irrigation because high levels are toxic to many plants. However, chloride levels at WWTFs typically are not monitored. Even in the absence of saltwater infiltration, industrial contributions or practices within the community being served may adversely impact reclaimed water quality. The widespread use of water softeners may increase the concentration of salts to levels that make the reclaimed water unusable for some applications. High chlorides from saltwater infiltration led the City of Punta Gorda, Florida to cease reclaimed water irrigation in 2001. This facility had irrigated an underdrained agricultural site for almost 20 years, but flow discharged from the underdrains caused a violation of conductivity limitations in the receiving water.

Damage to landscape plants in the City of St. Petersburg, Florida, was traced to elevated chlorides in the reclaimed water. This coastal city operates 4 reclamation plants and those serving older beach communities are prone to saltwater infiltration. In response to this problem, the City initiated on-line monitoring of conductance in order to identify and halt the use of unacceptable water. The City also developed a planting guide for reclaimed water customers to identify foliage more and less suitable for use with reclaimed water service (Johnson, 1998). The Carmel Area Wastewater District in California experienced a similar problem with golf course turf associated with elevated sodium. This was due to a combination of the potable water treatment processes being used, and the prevalence of residential and commercial water softeners. Solutions included the use of gypsum, periodic use of potable water for irrigation to flush the root zone, a switch from sodium hydroxide to potassium hydroxide for corrosion control, and attempts to reduce the use of self-regenerating water softeners (Sheikh *et al.,* 1997). Some coastal communities, or areas where salinity is a concern, have begun to restrict the discharge of chemical salts into the sanitary sewer system either by requiring their placement in a special brine line or by charging a fee for their treatment and removal (Sheikh and Rosenblum, 2002). A California state law recently gave local jurisdictions the ability to prohibit the use of self-regenerating water softeners that had been previously exempt from regulation by a prior statute (California Health and Safety Code).

The West Basin Municipal Water District in southwest Los Angeles County, California, created designer reclaimed water of different qualities to increase their reclaimed water customer base. **Table 3-1** describes the 5 different grades of designer water they produce and supply to their 200-square mile area of customers.

For the purpose of reuse planning, it is best to consider reclaimed water quality from the standpoint of water supply, (i.e., what quality is required for the intended use?). Where a single large customer dominates the demand for reclaimed water, the treatment selected may suit that particular, major customer. In Pomona, California, activated carbon filters were used in place of conventional sand filters at the reclamation plant to serve paper mills that require low color in their water supply.

Industrial reuse might be precluded if high levels of dissolved solids, dissolved organic material, chlorides, phosphates, and nutrients are present, unless additional treatment is provided by the industrial facility. Recreational reuse might be limited by nutrients, which could result in unsightly and odorous algae blooms. Trace metals in high concentrations might restrict the use of reclaimed water for agricultural and horticultural irrigation.

3.3.2.3 Reclaimed Water Quantity

Just as the potable water purveyor must meet diurnal and seasonal variations in demand, so too must the purveyor meet variations in demand for reclaimed water. Diurnal and seasonal fluctuations in supply and demand must be taken into account at the preliminary design stage of any water reclamation system. Such an approach is warranted, given the fact that diurnal and seasonal supplies and demands for reclaimed water often exhibit more variations than that of potable water and, in many cases, the peaks in supply and demand are independent of one another.

For example, WWTF flows tend to be low at night, when urban irrigation demand tends to be high. Seasonal flow fluctuations may occur in resort areas due to the influx

Table 3-1. Five Grades of Reclaimed Water Produced by West Basin MWD

Grade	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Name	Tertiary	Nitrified	Pure RO	Softened RO	Ultra-Pure RO
Treatment	Secondary effluent; additional filtration and disinfection	Tertiary water with ammonia removal	Secondary water plus micro filtration and RO	Grade 3 plus lime softening treatment	Double pass RO
Use	Landscape; golf course irrigation	Cooling towers	Low pressure boiler feed for refineries	Indirect potable reuse for the Water Replenishment District	High pressure boiler feed for refineries
Quality Drivers	Human contact and health requirements	Need to remove ammonia to reduce corrosion	Need to reduce contaminants that cause scaling; strong desire to use the water multiple times in the process	Softening the water preserves the pipes that deliver the water to the injection wells. Micro-filtration and RO have been perceived as providing acceptable treatment for indirect potable reuse.	High pressure increases the need to further reduce contaminants that cause scaling. Desire to use the water multiple times in the process
Reliability	No contractual guarantee; 100% reliable due to constant source	No information provided	No contractual guarantees	No contractual guarantees. May be perceived as more reliable	No contractual guarantees. Probably perceived as more reliable
Price	25 - 40% discount from baseline standard	Approximately 20% discounted from baseline standard	Equal to baseline standard or slightly higher	20% discount from baseline standard	100% price premium compared to the baseline standard
2001-02 Volume (AF)	2,600	8,300	6,500	7,300	2,600

Adapted from: “West Basin Municipal Water District: 5 Designer (Recycled) Waters to Meet Customer’s Needs” produced by Darryl G. Miller, General Manager, West Basin Municipal Water District, Carson, California.

of tourists, and seasons of high flow do not necessarily correspond with seasons of high irrigation demand. **Figure 3-9** illustrates the fluctuations in reclaimed water supply and irrigation demand in a southwest Florida community. Treatment facilities serving college campuses, resort areas, etc. also experience significant fluctuations in flow throughout the year. Where collection systems are prone to infiltration and inflow, significant fluctuations in flow may occur during the rainy season.

Information about flow quantities and fluctuations is critical in order to determine the size of storage facilities needed to balance supply and demand in water reuse systems. A more detailed discussion of seasonal storage requirements is provided in Section 3.5. Operational storage requirements to balance diurnal flow variations are detailed in Section 3.6.3.

3.3.2.4 Industrial Wastewater Contributions

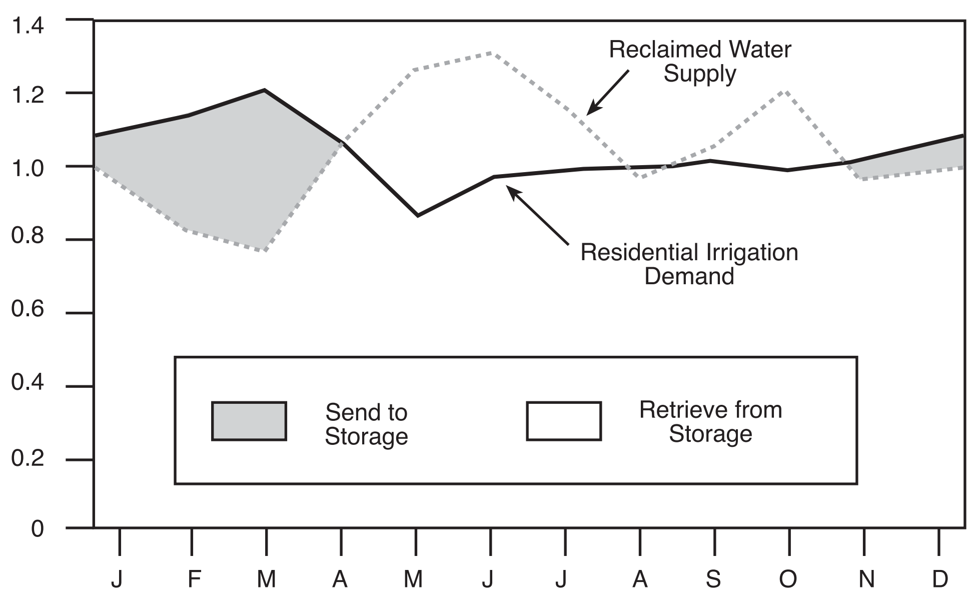
Industrial waste streams differ from domestic wastewater in that they may contain relatively high levels of elements and compounds, which may be toxic to plants and animals or may adversely impact treatment plant performance. Where industrial wastewater flow contributions to the WWTF are significant, reclaimed water quality may be affected. The degree of impact will, of course, depend on the nature of the industry. A rigorous pretreatment program is required for any water reclamation facility that receives industrial wastes to ensure the reliability of the biological treatment processes by excluding potentially toxic levels of pollutants from the sewer system. Planning a reuse system for a WWTF with substantial industrial flows will require identification of the constituents that may interfere with particular reuse applications, and appropriate monitoring for parameters of concern. Wastewater treatment facilities receiving substantial amounts of high-strength industrial wastes may be limited in the number and type of suitable reuse applications.

3.4 Treatment Requirements for Water Reuse

One of the most critical objectives in any reuse program is to ensure that public health protection is not compromised through the use of reclaimed water. To date there have not been any confirmed cases of infectious disease resulting from the use of properly treated reclaimed water in the U.S. Other objectives, such as preventing environmental degradation, avoiding public nuisance, and meeting user requirements, must also be satisfied, but the starting point remains the safe delivery and use of properly treated reclaimed water.

Protection of public health is achieved by: (1) reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water, (2) controlling chemical constituents in reclaimed water, and/or (3) limiting public exposure (contact, inhalation, ingestion) to reclaimed water. Reclaimed water projects may vary significantly in the level of human exposure incurred, with a corresponding variation in the potential for health risks. Where human exposure is likely in a reuse application, reclaimed water should be treated to a high degree prior to its use. Conversely, where public access to

Figure 3-9. Reclaimed Water Supply vs. Irrigation Demand



a reuse site can be restricted so that exposure is unlikely, a lower level of treatment may be satisfactory, provided that worker safety is not compromised.

Determining the necessary treatment for the intended reuse application requires an understanding of the:

- Constituents of concern in wastewater
- Levels of treatment and processes applicable for reducing these constituents to levels that achieve the desired reclaimed water quality

3.4.1 Health Assessment of Water Reuse

The types and concentrations of pathogenic organisms found in raw wastewater are a reflection of the enteric organisms present in the customer base of the collection system. Chemical pollutants of concern may also be present in untreated wastewater. These chemicals may originate from any customer with access to the collection system, but are typically associated with industrial customers. Recent studies have shown that over-the-counter and prescription drugs are often found in wastewater.

The ability for waterborne organisms to cause disease is well established. Our knowledge of the hazards of chemical pollutants varies. In most cases, these concerns are based on the potential that adverse health effects may occur due to long-term exposure to relatively low concentrations. In addition, chemicals capable of mimicking hormones have been shown to disrupt the endocrine systems of aquatic animals.

In order to put these concerns into perspective with respect to water reclamation, it is important to consider the following questions.

- What is the intended use of the reclaimed water?

  Consideration should be given to the expected degree of human contact with the reclaimed water. It is reasonable to assume that reclaimed water used for the irrigation of non-food crops on a restricted agricultural site may be of lesser quality than water used for landscape irrigation at a public park or school, which in turn may be of a lesser quality than reclaimed water intended to augment potable supplies.

- Given the intended use of reclaimed water, what concentrations of microbiological organisms and chemicals of concern are acceptable?

  Reclaimed water quality standards have evolved over a long period of time, based on both scientific studies and practical experience. Chapter 4 provides a summary of state requirements for different types of reuse projects. While requirements might be similar from state to state, allowable concentrations and the constituents monitored are state-specific. Chapter 4 also provides suggested guidelines for reclaimed water quality as a function of use.

- Which treatment processes are needed to achieve the required reclaimed water quality?

  While it must be acknowledged that raw wastewater may pose a significant risk to public health, it is equally important to point out that current treatment technologies allow water to be treated to almost any quality desired. For many uses of reclaimed water, appropriate water quality can be achieved through conventional, widely practiced treatment processes. Advanced treatment beyond secondary treatment may be required as the level of human contact increases.

- Which sampling/monitoring protocols are required to ensure that water quality objectives are being met?

  As with any process, wastewater reuse programs must be monitored to confirm that they are operating as expected. Once a unit process is selected, there are typically standard Quality Assurance/Quality Control (QA/QC) practices to assure that the system is functioning as designed. Reuse projects will often require additional monitoring to prevent the discharge of substandard water to the reclamation system. On-line, real-time water quality monitoring is typically used for this purpose.

3.4.1.1 Mechanism of Disease Transmission

For the purposes of this discussion, the definition of disease is limited to illness caused by microorganisms. Health issues associated with chemical constituents in reclaimed water are discussed in Section 3.4.1.7. Diseases associated with microorganisms can be transmitted by water to humans either directly by ingestion, inhalation, or skin contact of infectious agents, or indirectly by contact with objects or individuals previously contaminated. The following circumstances must occur for an individual to become infected through exposure to reclaimed water: (a) the infectious agent must be present in the community and, hence, in the wastewater from that community; (b) the agents must survive, to a significant degree, all of the wastewater treatment processes to which they are exposed; (c) the individual must either directly or indirectly come into contact with the reclaimed water; and (d) the agents must be present in sufficient numbers to cause infection at the time of contact.

The primary means of ensuring reclaimed water can be used for beneficial purposes is first to provide the appropriate treatment to reduce or eliminate pathogens. Treatment processes typically employed in water reclamation systems are discussed below and in Section 3.4.2. Additional safeguards are provided by reducing the level of contact with reclaimed water. Section 3.6 discusses a variety of cross-connection control measures that typically accompany reuse systems.

The large variety of pathogenic microorganisms that may be present in raw domestic wastewater is derived principally from the feces of infected humans and primarily transmitted by consumption. Thus, the main transmission route is referred to as the "fecal-oral" route. Contaminated water is an important conduit for fecal-oral transmission to humans and occurs either by direct consumption or by the use of contaminated water in agriculture and food processing. There are occasions when host infections cause passage of pathogens in urine. The 3 principal infections leading to significant appearance of pathogens in urine are: urinary schistosomiasis, typhoid fever, and leptospirosis. Coliform and other bacteria may be numerous in urine during urinary tract infections. Since the incidence of these diseases in the U.S. is very low, they constitute little public health risk in water reuse. Microbial agents resulting from venereal infections can also be present in urine, but they are so vulnerable to conditions outside the body that wastewater is not a predominant vehicle of transmission (Feachem *et al*., 1983 and Riggs, 1989).

3.4.1.2 Pathogenic Microorganisms and Health Risks

The potential transmission of infectious disease by pathogenic agents is the most common concern associated with reuse of treated municipal wastewater. Fortunately, sanitary engineering and preventive medical practices have combined to reach a point where waterborne disease outbreaks of epidemic proportions have, to a great extent, been controlled. However, the potential for disease transmission through water has not been eliminated. With few exceptions, the disease organisms of epidemic history are still present in today's sewage. The level of treatment today is more related to severing the transmission chain than to fully eradicating the disease agents.

Many infectious disease microbes affecting individuals in a community can find their way into municipal sewage. Most of the organisms found in untreated wastewater are known as enteric organisms; they inhabit the intestinal tract where they can cause disease, such as diarrhea. **Table 3-2** lists many of the infectious agents potentially present in raw domestic wastewater. These microbes can be classified into 3 broad groups: bacteria, parasites (parasitic protozoa and helminths), and viruses. Table 3-2 also lists the diseases associated with each organism.

a. Bacteria

Bacteria are microscopic organisms ranging from approximately 0.2 to 10 µm in length. They are distributed ubiquitously in nature and have a wide variety of nutritional requirements. Many types of harmless bacteria colonize in the human intestinal tract and are routinely shed in the feces. Pathogenic bacteria are also present in the feces of infected individuals. Therefore, municipal wastewater can contain a wide variety and concentration range of bacteria, including those pathogenic to humans. The numbers and types of these agents are a function of their prevalence in the animal and human community from which the wastewater is derived. Three of the more common bacterial pathogens found in raw wastewater are *Salmonella* sp, *Shigella* sp. and enteropathogenic *Escherichia coli* which have caused drinking water outbreaks with significant numbers of cases of hemolytic uremic syndrome (HUS) and multiple deaths (e.g. Walkerton, Ontario; Washington County, NY; Cabool, MO; Alpine, WY).

Bacterial levels in wastewater can be significantly lowered through either a "removal" or an "inactivation" process. The removal process involves the physical separation of the bacteria from the wastewater through sedimentation and/or filtration. Due to density considerations, bacteria do not settle as individual cells or even colonies. Typically, bacteria can adsorb to particulate matter or floc particles. These particles settle during sedimentation, secondary clarification, or during an advanced treatment process such as coagulation/flocculation/sedimentation using a coagulant. Bacteria can also be removed by using a filtration process that includes sand filters, disk (cloth) filters, or membrane processes. Filtration efficiency for a sand or cloth filter is dependent upon the effective pore size of the filtering medium and the presence of a "pre-coat" layer, usually other particulate matter. Because the pore sizes inherent to microfiltration and ultrafiltration membranes (including those membranes used in membrane bioreactors), bacteria are, to a large extent, completely removed due to size exclusion. Ultimately, the sedimented or filtered bacteria are removed from the overall treatment system through the sludge and backwash treatment system.

Table 3-2. Infectious Agents Potentially Present in Untreated Domestic Wastewater

Pathogen	Disease
Bacteria	
Shigella (spp.)	Shigellosis (bacillary dysentery)
Salmonella typhi	Typhoid fever
Salmonella (1700 serotypes spp.)	Salmonellosis
Vibro cholerae	Cholera
Escherichia coli (enteropathogenic)	Gastroenteritis and septicemia, hemolytic uremic syndrome (HUS)
Yersinia enterocolitica	Yersiniosis
Leptospira (spp.)	Leptospirosis
Campylobacter jejune	Gastroenteritis, reactive arthritis
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery)
Giardia lamblia	Giardiasis (gastroenteritis)
Cryptosporidium	Cryptosporidiosis, diarrhea, fever
Microsporidia	Diarrhea
Helminths	
Ascaris lumbricoides	Ascariasis (roundworm infection)
Ancylostoma (spp)	Ancylostomiasis (hookworm infection)
Necator americanus	Necatoriasis (roundworm infection)
Ancylostoma (spp.)	Cutaneous larva migrams (hookworm infection)
Strongloides stercoralis	Strongyloidiasis (threadworm infection)
Trichuris trichiura	Trichuriasis (whipworm infection)
Taenia (spp.)	Taeniasis (tapeworm infection)
Enterobius vermicularis	Enterobiasis (pinwork infection)
Echinococcus granulosus (spp.)	Hydatidosis (tapeworm infection)
Viruses	
Enteroviruses (polio, echo, coxsackie, new enteroviruses, serotype 68 to 71)	Gastroenteritis, heart anomolies, meningitis, others
Hepatitis A and E virus	Infectious hepatitis
Adenovirus	Respiratory disease, eye infections, gastroenteritis (serotype 40 and 41)
Rotavirus	Gastroenteritis
Parvovirus	Gastroenteritis
Noroviruses	Diarrhea, vomiting, fever
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis
Coronavirus	Gastroenteritis

Source: Adapted from National Research Council, 1996; Sagik *et. al*., 1978; and Hurst *et. al.,* 1989

Inactivation of bacteria refers to the destruction (death) of bacteria cells or the interference with reproductive ability using a chemical or energy agent. Such inactivation is usually referred to as disinfection. The most common disinfectants used in wastewater treatment are free chlorine, chloramines, ultraviolet (UV) light, and ozone. Chlorine, a powerful chemical oxidant, generally inactivates bacterial cells by causing physiological damage to cell membranes and damage to the internal cell components. Chloramines, chlorine substituted ammonia compounds, generally inactivate bacteria cells by disrupting DNA, thus causing direct cell death and/or inhibiting ability to reproduce. UV light also inactivates bacteria by damaging the DNA, thus inhibiting the ability to reproduce. Ozone, another powerful oxidant, can cause cell inactivation by direct damage to the cell wall and membrane, disruption of enzymatic reaction, and damage to DNA. The relative effectiveness of each chemical disinfectant is generally related to the product of disinfectant concentration and the disinfectant contact time. This product is commonly referenced as the "Ct" value. Tables of various Ct values required to inactivate bacteria (and other pathogens, such as viruses and protozoans) are readily available in the literature for clean (filtered) water applications. These Ct values are a function of temperature, pH, and the desired level of inactivation.

In recognition of the many constraints associated with analyzing wastewater for all of the potential pathogens that may be present, it has been common practice to use a microbial indicator or surrogate to indicate fecal contamination of water. Some bacteria of the coliform group have long been considered the prime indicators of fecal contamination and are the most frequently applied indicators used by state regulatory agencies to monitor water quality. The coliform group is composed of a number of bacteria that have common metabolic attributes. The total coliform groups are all gram-negative aspogenous rods, and most are found in feces of warm-blooded animals and in soil. Fecal coliforms are, for the most part, bacteria restricted to the intestinal tract of warm-blooded animals and comprise a portion of the total coliform group. Coliform organisms are used as indicators because they occur naturally in the feces of warm-blooded animals in higher concentrations than pathogens, are easily detectable, exhibit a positive correlation with fecal contamination, and generally respond similarly to environmental conditions and treatment processes as many bacterial pathogens. Where low levels of coliform organisms are used to indicate the absence of pathogenic bacteria, there is consensus among microbiologists that the total coliform analysis is not superior to the fecal coliform analysis. Specific methods have been developed to detect and enumerate *Escherichia coli* for use as a potential indicator organism.

b. Parasitic Protozoa and Helminths

The most common parasites in domestic untreated wastewater include several genera in the microspora, protozoa, trematode, and nematode families. Since the parasites cannot multiply in the environment, they require a host to reproduce and are excreted in the feces as spores, cysts, oocysts, or eggs, which are robust and resistant to environmental stresses such as dessication, heat, and sunlight. Most parasite spores, cysts, oocysts, and eggs are larger than bacteria and range in size from 1 µm to over 60 µm. While these parasites can be present in the feces of infected individuals who exhibit disease symptoms, carriers with unapparent infections can also excrete them, as may be the case with bacteria and viral infections as well. Furthermore, some protozoa such as *Toxoplasma* and *Cryptosporidium* are among the most common opportunistic infections in patients with acquired immunodeficiency syndrome (AIDS) (Slifko *et al.,* 2000). There are several helminthic parasites that occur in wastewater. Examples include the roundworm *Ascaris* as well as other nematodes such as the hookworms and pinworm. Many of the helminths have complex life cycles, including a required stage in intermediate hosts. The infective stage of some helminths is either the adult organism or larvae, while the eggs or ova of other helminths constitute the infective stage of the organisms. The eggs and larvae, which range in size from about 10 µm to more than 100 µm, are resistant to environmental stresses and may survive usual wastewater disinfection procedures. Helminth ova are readily removed by commonly used wastewater treatment processes such as sedimentation, filtration, or stabilization ponds. A 1992 study in St. Petersburg, Florida, showed helminths were completely removed in the secondary clarifiers (Rose and Carnahan, 1992).

In recent years, the protozoan parasites have emerged as a significant human health threat in regards to chlorinated drinking water. In particular, the protozoa such as *Giardia lamblia*, *Cryptosporidium pavum*, and *Cyclospora cayetanensis* have caused numerous waterborne and/or foodborne outbreaks. *Microsporidia* spp. have also been implicated as a waterborne pathogen (Cotte *et al.,* 1999).

Protozoan pathogens can be reduced in wastewater by the same previously described mechanisms of removal and inactivation. *Cryptosporidium* oocysts are 4 to 6 mm in diameter while *Giardia* cysts range between 8 to 16 mm in diameter. Due to the relatively large size compared to bacteria, the protozoa can be removed by properly designed and operated sedimentation and filtration systems commonly employed in wastewater and water treatment. In terms of inactivation, commonly used disinfectants such as chlorine are not as effective for inactivating the protozoa as compared to bacteria and viruses. **Table 3-3** shows the relative microbial resistance to disinfection compared to *E. coli.* For the chemical disinfectants, a higher Ct value is required to show an equal level of inactivation as compared to bacteria. Advanced disinfection using irradiation such as UV or electron beam treatments have been shown to be effective for inactivating the pathogens with the necessary fluence or dose being roughly equivalent to that required by some bacteria.

c. Viruses

Viruses are obligate intracellular parasites able to multiply only within a host cell and are host-specific. Viruses occur in various shapes and range in size from 0.01 to 0.3 µm in cross-section and are composed of a nucleic acid core surrounded by an outer coat of protein. Bacteriophage are viruses that infect bacteria as the host; they have not been implicated in human infections and are often used as indicators in seeded virus studies. Coliphages are host specific viruses that infect the coliform bacteria.

Enteric viruses multiply in the intestinal tract and are released in the fecal matter of infected persons. Not all types of enteric viruses have been determined to cause waterborne disease, but over 100 different enteric viruses are capable of producing infections or disease. In general, viruses are more resistant to environmental stresses than many of the bacteria, although some viruses persist for only a short time in wastewater. The Enteroviruses, Rotavirus, and the Enteric Adenoviruses, which are known to cause respiratory illness, gastroenteritis, and eye infections, have been isolated from wastewater. Of the viruses that cause diarrheal disease, only the Noroviruss and Rotavirus have been shown to be major waterborne pathogens (Rose, 1986) capable of causing large outbreaks of disease.

There is no evidence that the Human Immunodeficiency Virus (HIV), the pathogen that causes AIDS, can be transmitted via a waterborne route (Riggs, 1989). The results of one laboratory study (Casson *et al*., 1992), where primary and undisinfected secondary effluent samples were inoculated with HIV (Strain IIIB) and held for up to 48 hours at 25° C (77° F), indicated that HIV survival was significantly less than Polio virus survival under similar conditions. A similar study by Casson *et al*. in 1997 indicated that untreated wastewater spiked with blood cells infected with the HIV exhibited a rapid loss of HIV, although a small fraction remained stable for 48 hours.

Similar to bacteria and protozoan parasites, viruses can be both physically removed from the wastewater or inactivated. However, due to the relatively small size of typical viruses, the sedimentation and filtration processes are less effective at removal. Significant virus removal can be achieved with ultrafiltration membranes, possibly in the 3- to 4-log range. However, for viruses, inactivation is generally considered the more important of the 2 main reduction methods. Due to the size and relatively noncomplex nature of viruses, most disinfectants demonstrate reasonable inactivation levels at relatively low Ct values. Interestingly, for UV light disinfection, relatively high fluence values are required to inactivate viruses when compared to bacteria and protozoans. It is believed that the protein coat of the virus shields the ribonucleic acid (RNA) from UV light.

3.4.1.3 Presence and Survival of Pathogens

a. Presence

Bacteria, viruses, and parasites can all be detected in wastewater. Studies of pathogens have reported average levels of 6.2, 5.8, and 5.3 log cfu/100ml of *Yersinia, Shigella,* and *Salmonella* detected in primary-clarified sewage influent over a 2-year period in a U.S. facility (Hench *et al.,* 2003). *Salmonella* may be present in concentrations up to 10,000/l. The excretion of *Salmonella typhi* by asymptomatic carriers may vary from 5 x 10^3 to 45 x 10^6 bacteria/g of feces. But there are few studies in recent years, which have directly investigated the presence of bacterial pathogens and have focused more often on the indicator bacteria. Concentrations excreted by infected individuals range from 10^6 cysts, 10^7 oocysts and as high as 10^{12} virus particle per gram of feces for *Giardia*, *Cryptosporidium,* and *Rotavirus*, respectively (Gerba, 2000). Pathogen levels in wastewater can vary depending on infection in the community.

Levels of viruses, parasites, and indicator bacteria reported in untreated and secondary treated effluents are shown in **Tables 3-4** and **3-5**. These tables illustrate the tremendous range in the concentrations of microorgan-

Table 3-3. Ct Requirements for Free Chlorine and Chlorine Dioxide to Achieve 99 Percent Inactivation of *E. Coli* Compared to Other Microorganisms

Microbe	Cl_2 Ct	% Greater Cl_2 Ct Requirement Compared to *E. Coli*	Chloramine Ct	% Greater Chloramine Ct Requirement Compared to *E. Coli*
E. Coli	0.6	NA	113	NA
Poliovirus	1.7	96%	1,420	170%
Giardia	54-250	196-199%	430-580	117-135%
Cryptosporidium	>7,200	>200%	>7,200	>194%

Adapted from: Maier, 2000

isms that may be found in raw and secondary wastewater.

The methods currently used to detect *Cryptosporidium* oocysts and *Giardia* cysts are limited since they cannot assess viability or potential infectivity. Therefore, the health risks associated with finding oocysts and cysts in the environment cannot be accurately ascertained from occurrence data and the risks remain unknown.

Dowd *et al.* (1998) described a polymerase chain reaction (PCR) method to detect and identify the microsporidia (amplifying the small subunit ribosomal DNA of microsporidia). They found isolates in sewage, surface waters, and ground waters. The strain that was most often detected was *Enterocytozoon bieneusi*, which is a cause of diarrhea and excreted from infected individuals into wastewater. Microsporidia spores have been shown to be stable in the environment and remain infective for days to weeks outside their hosts (Shadduck, 1989; Waller, 1980; Shadduck and Polley, 1978). Because of their small size (1 to 5 µm), they may be difficult to remove using conventional filtration techniques. However, initial studies using cell culture suggest that the spores may be more susceptible to disinfection (Wolk *et al.,* 2000).

Under experimental conditions, absorption of viruses and *E. coli* through plant roots, and subsequent acropetal translocation has been reported (Murphy and Syverton, 1958). For example, one study inoculated soil with Polio virus, and found that the viruses were detected in the leaves of plants only when the plant roots were damaged or cut. The likelihood of translocation of pathogens through trees or vines to the edible portions of crops is extremely low, and the health risks are negligible.

Table 3-4. Microorganism Concentrations in Raw Wastewater

Organism	Range in Average Concentrations (CFU, PFU or Cysts/Oocysts)
Fecal Coliforms/100L	105 to 105
Enterococi/100L	10^4 to 10^5
Shigella /100mL	1 to 10^3
Salmonella /100mL	10^2 to 10^4
Helminth ova/100mL	1 to 10^3
Enteric virus/100L	1 to 5 x10^3
Giardia cysts/100L	0.39 to 4.9x10^4
Cryptosporidium oocysts/100L	0.2 to 1.5 x10^3

Source: NRC, 1998 and Maier *et. al*., 2000

Table 3-5. Microorganism Concentrations in Secondary Non-Disinfected Wastewater

Organism	Average Concentrations (CFU, PFU, or Cysts/Oocysts per 100L)
Fecal Coliforms	7,764
Enterococci	2,186
Enteric virus	20 to 650
Giardia cysts	5 to 2,297
Cryptosporidium oocysts	140

Source: NRC, 1998

b. Survival

Most pathogens do not increase in numbers outside of their host, although in some instances the ova of helminths do not mature to the larval stage until they are in the soil. In all cases, the numbers decrease at various rates, depending on a number of factors including the inherent biologic nature of the agent, temperature, pH, sunlight, relative humidity, and competing flora and fauna. Examples of relative survival times for some pathogens are given in **Table 3-6**. These values are intended to indicate relative survival rates only, and illustrate the various persistence of selected organisms.

3.4.1.4 Pathogens and Indicator Organisms in Reclaimed Water

There have been a number of studies regarding the presence of pathogens and indicator organisms in reclaimed water and such studies continue as experience in this field expands. Koivunen *et al.* (2003) compared the reduction of fecal coliforms to the reduction of S*almonella* by conventional biological treatment, filtration, and disinfection. Fecal coliform bacteria were present at 1000-fold greater concentration, and the *Salmonella* bacteria were reduced to non-detectable levels by advanced treatment (greater than 99.9 percent). Fecal coliform bacteria were a good, conservative indicator of such reductions. However, given the numbers of *Salmonellae* in secondary effluents and the fact that 18 carried multiple antibiotic resistance, the authors concluded that without proper additional advanced treatment, there may be a significant public health risk.

A year-long study investigated a conventional reuse treatment facility in St. Petersburg, Florida (Rose *et al*., 1996). In this facility, deep-bed sand filtration and disinfection, with total chlorine residual (4 to 5 mg/L) were the barriers assessed through both monitoring of naturally occurring bacteria, protozoa, and viruses, as well as through seeded challenge studies. Removals were 5 log for human vi-

Table 3-6. Typical Pathogen Survival Times at 20-30 °C

Pathogen	Survival Time (days)		
	Fresh Water & Sewage	Crops	Soil
Viruses[a]			
Enteroviruses[b]	<120 but usually <50	<60 but usually <15	<100 but usually <20
Bacteria			
Fecal coliforms[a,c]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Salmonella spp.[a]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Shigella spp.[a]	<30 but usually <10	<10 but usually <5	---
Vibrio cholerae[d]	<30 but usually <10	<5 but usually <2	<20 but usually <10
Protozoa			
Entamoeba histolytica cysts	<30 but usually <15	<10 but usually <2	<20 but usually <10
Helminths			
Ascaris lumbricoides eggs	Many months	<60 but usually <30	Many months

a In seawater, viral survival is less and bacterial survival is very much less, than in fresh water.
b Includes polio-, echo-, and coxsackieviruses
c Fecal coliform is not a pathogen but is often used as an indicator organism
d *V. cholerae* survival in aqueous environments is a subject of current uncertainty.

Source: Adapted from Feacham *et. al*., 1983

ruses and coliphage indicators, with anywhere from 1.5 to 3 log reductions by disinfection. A 3 log reduction for protozoa was achieved and greater than 1 log reduction was achieved for bacteria and indicators. Protozoan viability was not evaluated. In this study, *Enterococci* and *Clostridium* were not included as alternative indicators. Only the phage was used as a virus indicator. Seeded trials using bacteriophage demonstrated a 1.5 and 1.6 log reduction by filtration and disinfection, respectively.

A second study was done at the Upper Occoquan Sewage Authority (UOSA) in Fairfax County, Virginia. Samples were collected once per month for 1 year from 8 sites from the advanced wastewater reclamation plant (Rose *et al.,* 2000). The 8 sites were monitored for indicator bacteria, total and fecal coliforms, enterococci, *Clostridium,* coliphage (viruses which infect *E.coli*), human enteric viruses, and enteric protozoa. Multimedia filtration reduced the bacteria by approximately 90 percent, but did not effectively reduce the coliphage or enteroviruses. The enteric protozoa were reduced by 85 to 95.7 percent. Chemical lime treatment was the most efficient barrier to the passage of microorganisms (reducing these microorganisms by approximately 99.99 percent for bacteria, 99.9 percent for *Clostridium* and enteroviruses, and 99 percent for protozoa). Disinfection was achieved through chlorination (free chlorine residuals of 0.2 to 0.5 mg/l), and effectively achieved another 90 to 99 percent reduction. Overall, the plant was able to achieve a 5 to 7 log reduction of bacteria, 5 log reduction of enteroviruses, 4 log reduction of *Clostridium*, and 3.5 log reduction of protozoa. Total coliforms, enterococci, *Clostridium*, coliphage, *Cryptosporidium,* and *Giardia* were detected in 4 or fewer samples of the final effluent. No enteroviruses or fecal coliforms were detected. Protozoa appeared to remain the most resistant microorganisms found in wastewater. However, as with the St. Petersburg study, protozoan viability in these studies was not addressed.

Table 3-7 provides a summary of influent and effluent microbiological quality for the St. Petersburg and Upper Occaquan studies for enterovirus, *Cryptosporidium,* and *Giardia*. Enteroviruses were found 100 percent of the time in untreated wastewater. The enteric protozoa, *Cryptosporidium,* and *Giardia* were found from 67 to 100 percent of the time in untreated wastewater. *Giardia* cysts were found to be more prevalent, and at higher concentrations than oocysts in wastewater, perhaps due to the increased incidence of infection in populations compared to cryptosporidiosis and higher asymptomatic infections. Levels of oocysts in sewage are similar throughout the world (Smith and Rose, 1998). However, crops irrigated with wastewater of a poorer quality in

Table 3-7 Pathogens in Untreated and Treated Wastewater

City	Organism	Untreated Wastewater		Reclaimed Water	
		% Positive	Average Value	% Positive	Average Value
St. Petersburg, FL	Enterovirus (PFU/100l)	100	1,033	8	0.01
	Cryptosporidium (oocysts/100l)	67	1,456	17	0.75
	Giardia (cysts/100l)	100	6,890	25	0.49
Upper Occoquan, VA	Enterovirus (PFU/100l)	100	1,100	0	0
	Cryptosporidium (oocysts/100l)	100	1,500	8.3	0.037
	Giardia (cysts/100l)	100	49,000	17	1.1

Source: Walker-Coleman *et. al.,* 2002; Rose and Carnahan, 1992; Sheikh and Cooper, 1998; Rose *et. al.,* 2001; Rose and Quintero-Betancourt, 2002; and York *et. al.,* 2002

Israel contained more oocysts than cysts (Armon *et al.,* 2002).

The results of these studies indicate that the treatment processes employed are capable of significantly reducing or eliminating these pathogens.

The State of Florida recognizes that *Giardia* and *Cryptosporidium* are pathogens of increasing importance to water reclamation and now requires monitoring for these pathogens (Florida DEP, 1999). Results of this monitoring are presented in **Table 3-8**. The Florida facilities highlighted in this table generally feature secondary treatment, filtration, and high-level disinfection. **Table 3-9** includes the associated data from these facilities for TSS, turbidity, and total chlorine residual.

Visual inspection studies in Florida and elsewhere routinely found *Giardia* cysts and *Cryptosporidium* oocysts in reclaimed water that received filtration and high-level disinfection and was deemed suitable for public access uses. A number of more detailed studies which considered the viability and infectivity of the cysts and oocysts suggested that *Giardia* was likely inactivated by chlorine but 15 to 40 percent of detected *Cryptosporidium* oocysts may survive (Keller, 2002; Sheikh, 1999; Garcia, 2002; Genacarro, 2003; Quintero, 2003). Other studies evaluating UV and the electron beam as alternatives to chlorine disinfection found that both parasites were easily inactivated (Mofidi 2002 and Slifko 2001). Both *Giardia* cysts and *Cryptosporidium* oocysts required less than $10 mJ/cm^2$ for complete inactivation by UV (Mofidi 2002 and Slifko 2001).

In December 2003, the Water Environment Research Foundation (WERF) initiated a series of workshops on indicators for pathogens in wastewater, stormwater, and biosolids. The first workshop considered the state of science for indicator organisms. Potential indicators for further study were identified in an attempt to improve upon current indicator organism use and requirements. The results of this effort are summarized in **Table 3-10**. Subsequent phases of this effort will evaluate the usefulness of the selected list of indicators and compare them with current indicators. Detailed studies will then be conducted using the most promising indicators in field studies at various sites in the U.S.

3.4.1.5 Aerosols

Aerosols are defined as particles less than 50 µm in diameter that are suspended in air. Viruses and most pathogenic bacteria are in the respirable size range; hence, the inhalation of aerosols is a possible direct mean of human infection. Aerosols are most often a concern where reclaimed water is applied to urban or agricultural sites with sprinkler irrigation systems, or where it is used for cooling water make-up.

The concentration of pathogens in aerosols is a function of their concentration in the applied water and the aerosolization efficiency of the spray process. During spray irrigation, the amount of water that is aerosolized can vary from less than 0.1 percent to almost 2 percent, with a mean aerosolization efficiency of 1 percent or less. Infection or disease may be contracted indirectly by deposited aerosols on surfaces such as food, vegetation, and clothes. The infective dose of some pathogens is lower for respiratory tract infections than for infections via the gastrointestinal tract. Therefore, for some pathogens, inhalation may be a more likely route for disease transmission than either contact or ingestion.

The infectivity of an inhaled aerosol depends on the depth of the respiratory penetration and the presence of pathogenic organisms capable of infecting the respiratory sys-

Table 3-8. Summary of Florida Pathogen Monitoring Data

Statistic	*Giardia*	*Cryptosporidium*
Number of observations	69	68
% having detectable concentrations	58%	22%
25 percentile (#/100 l)	ND	ND
50 percentile (#/100 l)	4	ND
75 percentile (#/100 l)	76	ND
90 percentile (#/100 l)	333	2.3
Maximum (#/100 l)	3,096	282

Notes: (a) All numeric data are total numbers of cysts or oocysts per 100 L.
(b) ND indicates a value less than detection.
Source: Walker-Coleman, *et. al.,* 2002.

Table 3-9. Operational Data for Florida Facilities

Statistic	TSS (mg/l)	Turbidity (NTU)	Chlorine Residual (mg/l)
Minimum	0.19	0.31	1.01
10 percentile	0.4	0.45	1.9
25 percentile	0.8	0.65	2.32
50 percentile	1	0.99	4.1
75 percentile	1.76	1.36	5
90 percentile	2.1	1.8	7.1
Maximum	6	4.5	10.67

Source: Walker-Coleman *et. al.,* 2002

tem. Aerosols in the 2 to 5 µm size range are generally excluded from the respiratory tract, with some that are subsequently swallowed. Thus, if gastrointestinal pathogens are present, infection could result. A considerably greater potential for infection occurs when respiratory pathogens are inhaled in aerosols smaller than 2 µm in size, which pass directly to the alveoli of the lungs (Sorber and Guter, 1975).

One of the most comprehensive aerosol studies, the Lubbock Infection Surveillance Study (Camann *et al*., 1986), monitored viral and bacterial infections in a mostly rural community surrounding a spray injection site near Wilson, Texas. The source of the irrigation water was undisinfected trickling filter effluent from the Lubbock Southeast water reclamation plant. Spray irrigation of the wastewater significantly elevated air densities of fecal coliforms, fecal streptococci, mycobacteria, and coliphage above the ambient background levels for at least 650 feet (200 meters) downwind. The geometric mean concentration of enteroviruses recovered 150 to 200 feet (44 to 60 meters) downwind was 0.05 pfu/m^3, a level higher than that observed at other wastewater aerosol sites in the U.S. and in Israel (Camann *et al*., 1988). While disease surveillance found no obvious connection between the self-reporting of acute illness and the degree of aerosol exposure, serological testing of blood samples indicated that the rate of viral infections was slightly higher among members of the study population who had a high degree of aerosol exposure (Camann *et al*., 1986).

For intermittent spraying of disinfected reclaimed water, occasional inadvertent contact should pose little health hazard from inhalation. Cooling towers issue aerosols continuously, and may present a greater concern if the water is not properly disinfected. Although a great deal of effort has been expended to quantify the numbers of fecal coliforms and enteric pathogens in cooling tower waters, there is no evidence that they occur in large num-

Table 3-10 Some Suggested Alternative Indicators for Use in Monitoring Programs

Parameter	Pathogen Presence
Viruses	F+ RNA coliphages
	Somatic coliphages
	Adenovirus
	JC virus
Bacteria	*E. coli*
	Enterococci
	Bifidobacteria
Parasites	*Clostridium perfringens*
	Sulfite reducing
	Clostridium spp.
Non-microbial indicators	Fecal sterols
Pathogens as possible indicators	*Cryptosporidium*
	Giardia

Source: WERF Workshop, 2003

bers, although the numbers of other bacteria may be quite large (Adams and Lewis, n.d.).

No documented disease outbreaks have resulted from the spray irrigation of disinfected, reclaimed water. Studies indicate that the health risk associated with aerosols from spray irrigation sites using reclaimed water is low (U.S. EPA, 1980b). However, until more sensitive and definitive studies are conducted to fully evaluate the ability of pathogens contained in aerosols to cause disease, the general practice is to limit exposure to aerosols produced from reclaimed water that is not highly disinfected. Exposure is limited through design or operational controls. Design features include:

- Setback distances, which are sometimes called buffer zones
- Windbreaks, such as trees or walls around irrigated areas
- Low pressure irrigation systems and/or spray nozzles with large orifices to reduce the formation of fine mist
- Low-profile sprinklers
- Surface or subsurface methods of irrigation

Operational measures include:

- Spraying only during periods of low wind velocity
- Not spraying when wind is blowing toward sensitive areas subject to aerosol drift or windblown spray
- Irrigating at off-hours, when the public or employees would not be in areas subject to aerosols or spray

All these steps would be considered part of a best management plan for irrigation systems regardless of the source of water used.

Most states with reuse regulations or guidelines include setback distances from spray areas to property lines, buildings, and public access areas. Although predictive models have been developed to estimate microorganism concentrations in aerosols or larger water droplets resulting from spray irrigation, setback distances are determined by regulatory agencies in a somewhat arbitrary manner, using levels of disinfection, experience, and engineering judgment as the basis.

3.4.1.6 Infectious Disease Incidence Related to Wastewater Reuse

Epidemiological investigations have focused on wastewater-contaminated drinking water supplies, the use of raw or minimally-treated wastewater for food crop irrigation, health effects to farm workers who routinely contact poorly treated wastewater used for irrigation, and the health effects of aerosols or windblown spray emanating from spray irrigation sites using undisinfected wastewater. These investigations have all provided evidence of infectious disease transmission from such practices (Lund, 1980; Feachem *et al*., 1983; Shuval *et al*., 1986).

Review of the scientific literature, excluding the use of raw sewage or primary effluent on sewage farms in the late 19th century, does not indicate that there have been no confirmed cases of infectious disease resulting from reclaimed water use in the U.S. where such use has been in compliance with all appropriate regulatory controls. However, in developing countries, the irrigation of market crops with poorly treated wastewater is a major source of enteric disease (Shuval *et al.*, 1986).

Occurrences of low level or endemic waterborne diseases associated with exposure to reclaimed water have been difficult to ascertain for several reasons:

- Current detection methods have not been sufficiently sensitive or specific enough to accurately detect low concentrations of pathogens, such as viruses and protozoa, even in large volumes of water.
- Many infections are often not apparent, or go unreported, thus making it difficult to establish the endemicity of such infections.
- The apparently mild nature of many infections preclude reporting by the patient or the physician.
- Current epidemiological techniques are not sufficiently sensitive to detect low-level transmission of these diseases through water.
- Illness due to enteroviral or parasite infections may not become obvious for several months or years.
- Once introduced into a population, person-to-person contact can become a secondary mode of transmission of many pathogens, thereby obscuring the role of water in its transmission.

Because of the insensitivity of epidemiological studies to provide a direct empirical assessment of microbial health risk due to low-level exposure to pathogens, methodologies have increasingly relied on indirect measures of risk by using analytical models for estimation of the intensity of human exposure and the probability of human response from the exposure. Microbial risk assessment involves evaluating the likelihood that an adverse health effect may occur from human exposure to one or more potential pathogens. Most microbial risk assessments in the past have used a framework originally developed for chemicals that is defined by 4 major steps: (1) hazard identification, (2) dose-response identification, (3) exposure assessment, and (4) risk characterization. However, this framework does not explicitly acknowledge the differences between health effects due to chemical exposure versus those due to microbial exposure. Those differences include acute versus chronic health effects, potential for person-to-person transmission of disease, and the potential need to account for the epidemiological status of the population (Olivieri, 2002).

Microbial risk analyses require several assumptions to be made. These assumptions include a minimum infective dose of selected pathogens, concentration of pathogens present, quantity of pathogens ingested, inhaled, or otherwise contacted by humans, and probability of infection based on infectivity models. The use of microbial risk assessment models have been used extensively by the U.S. Department of Agriculture (USDA) to evaluate food safety for pathogens such as Listeria Monocytogenes in ready to eat foods (USDA, n.d.). The World Health Organization (WHO) and Food and Agriculture Organization (FAO) also provide risk assessment methodologies for use in evaluating food safety (Codex Alimentarius).

In order to assess health risks associated with the use of reclaimed water, pathogen risk assessment models to assess health risks associated with the use of reclaimed water have been used as a tool in assessing relative health risks from microorganisms in drinking water (Cooper *et al.,* 1986; Gerba and Haas, 1988; Olivieri *et al.,* 1986; Regli *et al*., 1991; Rose *et al*., 1991; Gale, 2002) and reclaimed water (Asano and Sakaji, 1990; EOA, Inc., 1995; Rose and Gerba, 1991; Tanaka *et al*., 1998; Patterson *et al*., 2001). Most of the models calculated the probability of individual infection or disease as a result of a single exposure. One of the more sophisticated models calculates a distribution of risk over the population by utilizing epidemiological data such as incubation period, immune status, duration of disease, rate of symptomatic development, and exposure data such as processes affecting pathogen concentration (EOA, Inc., 1995).

At the present time, no wastewater disinfection or reclaimed water standards or guidelines in the U.S. are based on risk assessment using microorganism infectivity models. Florida is investigating such an approach and has suggested levels of viruses between 0.04 to 14/100 l, depending on the virus (ranging from Rotavirus infectivity to a less infectious virus), viable oocysts at 22/100 l, and viable cysts at 5/100 l (York and Walker-Coleman, 1999). Microbial risk assessment methodology is a useful tool in assessing relative health risks associated with water reuse. Risk assessment will undoubtedly play a role in future criteria development as epidemiological-based models are improved and refined.

3.4.1.7 Chemical Constituents

The chemical constituents potentially present in municipal wastewater are a major concern when reclaimed water is used for potable reuse. These constituents may also affect the acceptability of reclaimed water for other uses, such as food crop irrigation or aquaculture. Potential mechanisms of food crop contamination include:

- Physical contamination, where evaporation and repeated applications may result in a buildup of contaminants on crops
- Uptake through the roots from the applied water or the soil, although available data indicate that potentially toxic organic pollutants do not enter edible portions of plants that are irrigated with treated municipal wastewater (National Research Council, 1996)
- Foliar uptake

With the exception of the possible inhalation of volatile organic compounds (VOCs) from indoor exposure, chemical concerns are less important where reclaimed water is not to be consumed. Chemical constituents are a consideration when reclaimed water percolates into groundwater as a result of irrigation, groundwater recharge, or other uses. These practices are covered in Chapter 2. Some of the inorganic and organic constituents in reclaimed water are listed in **Table 3-11**.

a. Inorganics

In general, the health hazards associated with the ingestion of inorganic constituents, either directly or through food, are well established (U.S. EPA, 1976). EPA has set maximum contaminant levels (MCLs) for drinking water. The concentrations of inorganic constituents in reclaimed water depend mainly on the source of wastewater and the degree of treatment. Residential use of water typically adds about 300 mg/l of dissolved inorganic solids, although the amount added can range from approximately 150 mg/l to more than 500 mg/l (Metcalf & Eddy, 2002). As indicated in Table 3-11 the presence of total dissolved solids, nitrogen, phosphorus, heavy metals, and other inorganic constituents may affect the acceptability of reclaimed water for different reuse applications. Wastewater treatment using existing technology can generally reduce many trace elements to below recommended maximum levels for irrigation and drinking water. Uses in wetlands and recreational surface waters must also consider aquatic life protection and wetland habitat.

b. Organics

The organic make-up of raw wastewater includes naturally occurring humic substances, fecal matter, kitchen wastes, liquid detergents, oils, grease, and other substances that, in one way or another, become part of the sewage stream. Industrial and residential wastes may contribute significant quantities of synthetic organic compounds.

The need to remove organic constituents is related to the end use of reclaimed water. Some of the adverse effects associated with organic substances include:

- Aesthetic effects – organics may be malodorous and impart color to the water
- Clogging – particulate matter may clog sprinkler heads or accumulate in soil and affect permeability
- Proliferation of microorganisms – organics provide food for microorganisms
- Oxygen consumption – upon decomposition, organic substances deplete the dissolved oxygen content in streams and lakes. This negatively impacts the aquatic life that depends on the oxygen supply for survival
- Use limitation – many industrial applications cannot tolerate water that is high in organic content
- Disinfection effects – organic matter can interfere with chlorine, ozone, and ultraviolet disinfection, thereby making them less available for disinfection purposes. Further, chlorination may result in formation of potentially harmful disinfection byproducts
- Health effects – ingestion of water containing certain organic compounds may result in acute or chronic health effects.

The wide range of anthropogenic organic contaminants in streams influenced by urbanization (including wastewater contamination) includes pharmaceuticals, hormones, antioxidants, plasticizers, solvents, polynuclear aromatic hydrocarbons (PAHs), detergents, pesticides, and their metabolites (Kolpin *et al.,* 2002). The stability and persistence of these compounds are extremely variable in the stream/sediment environment. A recent comprehensive study of the persistence of anthropogenic and natural organic molecules during groundwater recharge suggests that carbamezepine may survive long enough to serve as a useful tracer compound of wastewater origin (Clara *et al.,* 2004).

Table 3-11. Inorganic and Organic Constituents of Concern in Water Reclamation and Reuse

Constituent	Measured Parameters	Reasons for Concern
Suspended Solids	Suspended solids (SS), including volatile and fixed solids	Organic contaminants, heavy metals, etc. are absorbed on particulates. Suspended matter can shield microorganisms from disinfectants. Excessive amounts of suspended solids cause plugging in irrigation systems.
Biodegradable Organics	Biochemical oxygen demand, chemical oxygen demand, total organic carbon	Aesthetic and nuisance problems. Organics provide food for microorganisms, adversely affect disinfection processes, make water unsuitable for some industrial or other uses, consume oxygen, and may result in acute or chronic effects if reclaimed water is u
Nutrients	Nitrogen, Phosphorus, Potassium	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesir
Stable Organics	Specific compounds (e.g., pesticides, chlorinated hydrocarbons)	Some of these organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of reclaimed water for irrigation or other uses. Chlorine reacts with man
Hydrogen Ion Concentration	pH	The pH of wastewater affects disinfection, coagulation, metal solubility, as well as alkalinity of soils. Normal range in municipal wastewater is pH = 6.5 - 8.5, but industrial waste can alter pH significantly.
Heavy Metals	Specific elements (e.g., Cd, Zn, Ni, and Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the reclaimed water for irrigation or other uses.
Dissolved Inorganics	Total dissolved solids, electrical Conductivity, specific elements (e.g., Na, Ca, Mg, Cl, and B)	Excessive salinity may damage some crops. Specific inorganics electrical conductivity ions such as chloride, sodium, and boron are toxic to specific elements (e.g., in some crops, sodium may pose soil permeability Na, Ca, Mg, Cl, and B problems).
Residual Chlorine	Free and combined chlorine	Excessive amounts of free available chlorine (>0.05 Chlorine chlorine mg/l) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed water is in a combined form, which does not cause crop damage. Some concerns are expre

Source: Adapted from Pettygrove and Asano, 1985

The health effects resulting from organic constituents are of primary concern for indirect or direct potable reuse. In addition, these constituents may be of concern where reclaimed water is utilized for food crop irrigation, where reclaimed water from irrigation or other beneficial uses reaches potable groundwater supplies, or where the organics may bioaccumulate in the food chain (e.g., in fish-rearing ponds).

Traditional measures of organic matter such as BOD, chemical oxygen demand (COD), and total organic carbon (TOC), are widely used as indicators of treatment efficiency and water quality for many nonpotable uses of reclaimed water. However, these measures have only indirect relevance related to evaluating toxicity and health effects. Sophisticated analytical instrumentation makes it possible to identify and quantify extremely low levels of organic constituents in water. Examples include gas chromatography/tandem mass spectrometry (GC/MS/MS) or high performance liquid chromatography/mass spectrometry (HPLC/MS). These analyses are costly and may require extensive and difficult sample preparation, particularly for nonvolatile organics.

Organic compounds in wastewater can be transformed into chlorinated organic species where chlorine is used for disinfection purposes. In the past, most attention was focused on the trihalomethane (THM) compounds; a family of organic compounds typically occurring as chlorine or bromine-substituted forms of methane. Chloroform, a commonly found THM compound, has been implicated in the development of cancer of the liver and kidney. Improved analytical capabilities to detect extremely low levels of chemical constituents in water have resulted in identification of several health-significant chemicals and disinfection byproducts in recent years. For example, the extremely potent carcinogen, N-nitrosodimethylamine (NDMA) is present in sewage and is produced when municipal wastewater effluent is disinfected with chlorine or chloramines (Mitch *et al*, 2003). In some situations, the concentration of NDMA present in reclaimed water exceeds action levels set for the protection of human health, even after reverse osmosis treatment. To address concerns associated with NDMA and other trace organics in reclaimed water, several utilities in California have installed UV/H2O2 treatment systems for treatment of reverse osmosis permeate.

Quality standards have been established for many inorganic constituents. Treatment and analytical technology has demonstrated the capability to identify, quantify, and control these substances. Similarly, available technology is capable of eliminating pathogenic agents from contaminated waters. On the basis of available information, there is no indication that health risks from using highly treated reclaimed water for potable purposes are greater than those from using existing water supplies (National Research Council, 1994). Yet, unanswered questions remain about organic constituents, due mainly to their potentially large numbers and unresolved health risk potentials related to long-term, low-level exposure. Assessment of health risks associated with potable reuse is not definitive due to limited chemical and toxicological data and inherent limitations in available epidemiological and toxicological methods. The results of epidemiological studies directed at drinking water have generally been inconclusive, and extrapolation methodologies used in toxicological assessments provide uncertainties in overall risk characterization (National Research Council, 1998).

3.4.1.8 Endocrine Disrupters

In addition to the potential adverse effects of chemicals described in Section 3.4.1.6, certain chemical constituents present in wastewater also can disrupt hormonal systems. This phenomenon, which is referred to as endocrine disruption, can occur through a variety of mechanisms associated with hormone synthesis, hormone receptor binding, and hormone transformation. As a result of the many mechanisms through which chemicals can impact hormone function, a large number of chemicals are classified as endocrine disrupters. However, the exact types of chemicals that are classified as endocrine disrupters vary among researchers. **Table 3-12** highlights a number of example sources of potential endocrine disrupters.

For example, the oxyanion, perchlorate, is an endocrine disrupter because it affects the thyroid system (U.S. EPA, 2002). The herbicide, atrazine, is an endocrine disrupter because it affects an enzyme responsible for hormone regulation (Hayes *et al.* 2002). A USGS project recently sampled 139 streams in 30 states for any 1 of 95 endocrine disrupters. The results indicated that 80 percent of the streams had at least 1 of these compounds (McGovern and McDonald, 2003). The topic of endocrine disruption has significant implications for a wide variety of chemicals used by industry, agriculture, and consumers. As a result, the EPA, the European Union (EU), and other government organizations are currently evaluating approaches for regulating endocrine-disrupting chemicals.

With respect to water reuse, the greatest concerns associated with endocrine disruption are related to a series of field and laboratory studies demonstrating that chemicals in wastewater effluent caused male fish to exhibit female characteristics (Purdom *et al.,* 1994; Harries *et al.,* 1996; Harries *et al.,* 1997). This process, which is referred to as feminization, has been attributed mostly to the presence of steroid hormones excreted by humans

(Desbrow *et al.,* 1998 and Snyder *et al.,* 2001). The hormones involved in fish feminization include the endogenous (*i.e.,* produced within the body) hormone 17b-estradiol as well as hormones present in pharmaceuticals (*e.g.,* ethinyl estradiol in birth control pills). Other chemicals capable of feminizing fish are also present in wastewater. These include nonylphenol and alkylphenol polyethoxylates, both of which are metabolites of non-ionic detergents formed during secondary wastewater treatment (Ahel *et al.,* 1994).

The specific endocrine-disrupting chemicals in reclaimed water can be quantified using modern analytical methods. As indicated previously, the compounds most likely to be responsible for feminization of fish include steroid hormones (*e.g.,* 17b-estradiol and ethinyl estradiol) and detergents metabolites (*e.g.,* nonylphenol and alkylphenol polyethoxylates). Although these compounds cannot be quantified at the levels expected in reclaimed water with the gas chromatography/mass spectrometry (GC/MS) techniques routinely used to quantify priority pollutants, they can be measured with equipment available in many modern laboratories. For the hormones, analytical methods such as gas chromatography/tandem mass spectrometry (GC/MS/MS) (Ternes *et al.,* 1999, Huang and Sedlak, 2001), high performance liquid chromatography/mass spectrometry (HPLC/MS) (Ferguson *et al.,* 2001), or immunoassays (Huang and Sedlak, 2001 and Snyder *et al.,* 2001) are needed to detect the low concentrations present in wastewater effluent (*e.g.,* ethinyl estradiol concentrations are typically less than 2 υg/l in wastewater effluent). Although the endocrine-disrupting detergent metabolites are present at much higher concentrations than the hormones, their analysis also requires specialized analytical methods (Ahel *et al.,* 1994) not available from many commercial laboratories.

Bioassays can also be used to quantify the potential of reclaimed water to cause endocrine disruption. These methods are attractive because they have the potential to detect all of the difficult-to-measure endocrine-disrupting chemicals in 1 assay. The simplest bioassays involve *in vitro* tests, in which a hormone receptor from a mammalian cell is used to detect endocrine-disrupting chemicals. Among the different *in vitro* assays, the Yeast Estrogen Screen (YES) assay has been employed most frequently (Desbrow *et al.,* 1998). Comparisons between *in vitro* bioassays and chemical measurements yield

Table 3-12. Examples of the Types and Sources of Substances that have been Reported as Potential Endocrine-Disrupting Chemicals

Category	Examples of Substances	Examples of Uses	Examples of Sources
Polychlorinated Compounds	polychlorinated dioxins and polychlorinated biphenyls	industrial production of byproducts (mostly banned)	incineration and landfill runoff
Organochlorine Pesticides	DDT, dieldrin, and lindane	insecticides (many phased out)	agricultural runoff
Current Use Pesticides	atrazine, trifluralin, and permethrin	pesticides	agricultural runoff
Organotins	tributyltin	antifoulants on ships	harbors
Alkylphenolics	nonylphenol and octylphenol	surfactants (and their metabolites)	industrial and municipal effluents
Phthalates	dibutyl phthalate and butylbenzyl phthalate	plasticisers	industrial effluent
Sex Hormones	17-beta estradiol and estrone	produced naturally by animals	municipal effluents
Synthetic Steroids	ethinylestradiol	contraceptives	municipal effluents
Phytoestrogens	isoflavones, lignans, coumestans	present in plant material	pulp mill effluents

Source: Adapted from McGovern and McDonald, 2003 and Berkett and Lester, 2003 consistent results, indicating that steroid hormones are the most significant endocrine disrupting chemicals in wastewater effluent. Unfortunately, *in vitro* bioassays do not always detect compounds that disrupt hormone systems through mechanisms other than binding to hormone receptors. As a result, *in vivo* bioassays, usually performed with fish, may provide more accurate results. A clear dose-related response to various endocrine-disrupting compounds has been established in fish; however, little is known about species differences in sensitivity to exposure. Individual responses to exposure may also vary widely (Routledge *et al.*, 1998). Because many laboratories are unable to perform *in vivo* bioassays under the necessary conditions (*e.g.*, flow-through tests with rainbow trout), *in vivo* bioassays are not always practical. Available data suggest that nitrification/denitrification and filtration can reduce the concentrations of hormones and detergent metabolites while reverse osmosis lowers concentrations to levels that are unlikely to cause endocrine disruption (Huang and Sedlak, 2001 and Fujita *et al.,* 1996).

The current focus of research on disruption of the estrogen system may be attributable to the relative ease of detecting this form of endocrine disruption. As additional research is performed, other chemicals in wastewater effluent may be found to disrupt hormonal systems through mechanisms yet to be documented. For example, although results from *in vitro* bioassays suggest that the steroid hormones are most likely responsible for feminization of fish, it is possible that other endocrine disrupters contribute to the effect through mechanisms that cannot be detected by the bioassays.

The ecological implications associated with the feminization of fish are unknown. The potential of reclaimed water to cause endocrine disruption in humans is also unknown. It is anticipated that problems associated with endocrine disruption could occur, given prolonged consumption of substantial volumes of polluted water. The compounds in wastewater effluent that are believed to be responsible for feminization of fish may not pose a serious risk for humans because of differences between human and fish physiology. For example, the hormone 17b-estradiol is not used in the oral form in clinical applications because it would be metabolized before it could reach its target. Nevertheless, the evidence of endocrine disruption in wildlife and the absence of data about the effects of low-level exposure to endocrine disrupting compounds in humans has led to new scrutiny regarding endocrine-disrupting chemicals in reclaimed water.

3.4.2 Treatment Requirements

Untreated municipal wastewater may include contributions from domestic and industrial sources, infiltration and inflow from the collection system, and, in the case of combined sewer systems, urban stormwater runoff. The quantity and quality of wastewater derived from each source will vary among communities, depending on the number and type of commercial and industrial establishments in the area and the condition of the sewer system.

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. Advanced wastewater treatment, sometimes referred to as tertiary treatment, is generally defined as anything beyond secondary treatment. A generalized flow sheet for municipal wastewater treatment is shown in **Figure 3-10**.

In the last decade, significant advances were made in wastewater treatment equipment, design, and technology. For example, biological nutrient removal (BNR) processes have become more refined. Membranes are capable of producing higher quality effluent at higher flux rates and lower pressures than was possible before. Membrane bioreactors (MBRs) have shown to be effective in producing a high quality effluent, while greatly reducing a treatment plant's footprint. Microfiltration, used in some locations to replace conventional media filtration, has the advantage of effectively removing all parasite cysts (e.g., *Giardia* and *Cryptosporidium*). Advances in UV radiation technology have resulted in a cost competitive disinfection process capable of reducing the concentration of most pathogens to extremely low levels.

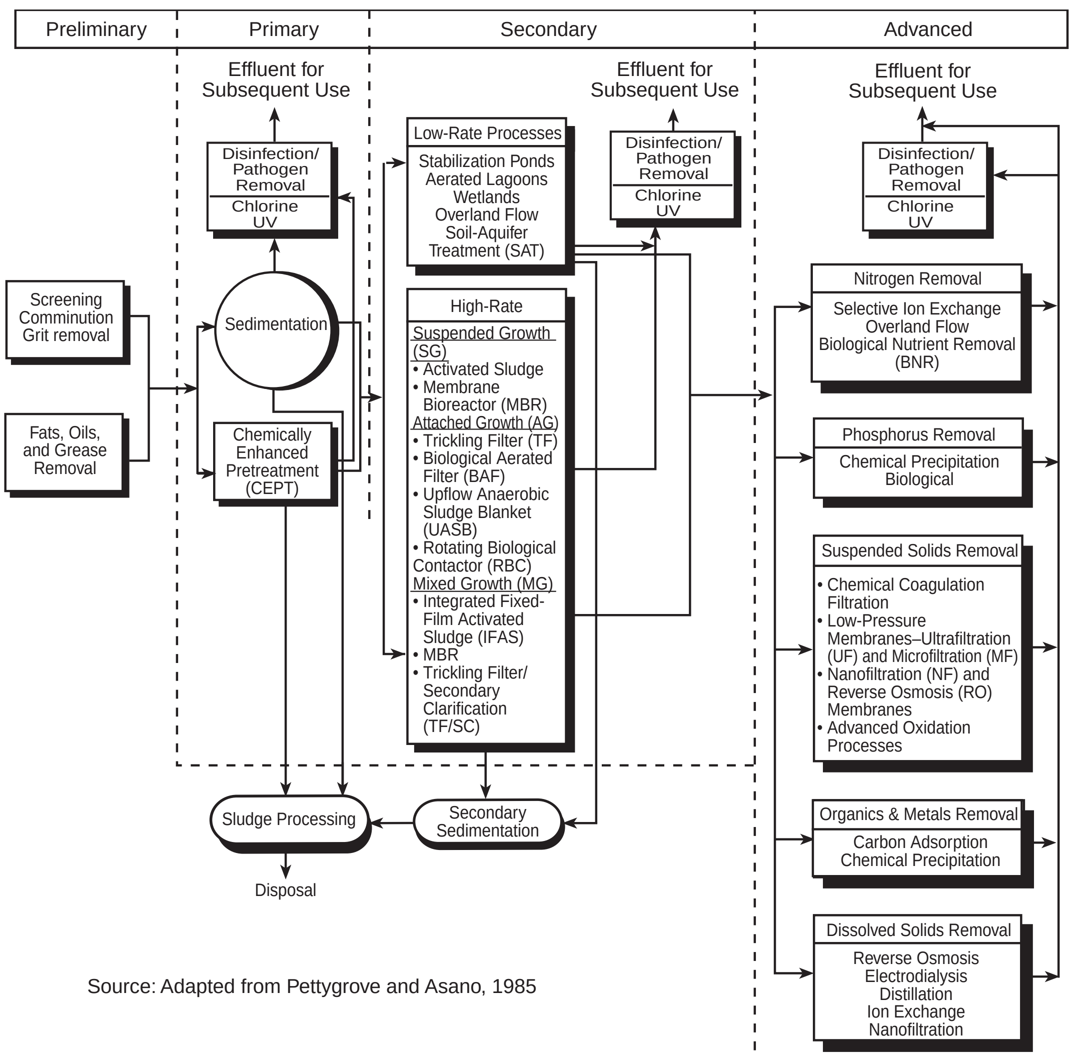
Wastewater treatment from raw to secondary is well understood and covered in great detail in other publications such as the Manual of Practice (MOP) 8, *Design of Municipal Wastewater Treatment Plants*, 4th Edition, (WEF, 1998). In this edition of the *Guidelines for Water Reuse* the discussion about treatment processes will be limited to those with a particular application to water reuse and reclamation. Such processes generally consist of disinfection and treatment beyond secondary treatment, although some limited access reuse programs may use secondary effluent without concern. It should be pointed out that treatment for particular pollutants at the water reclamation facility is not always the best answer. Source controls should also be investigated. In Orange County, California, 1,4-dioxane (listed as a probable human carcinogen based on animal studies) was found in 9 production wells at levels greater than the California action levels. This problem was solved by working with a treatment plant customer who voluntarily ceased discharge of 1,4-dioxane to the sewer system (Woodside and Wehner, 2002).

3.4.2.1 Disinfection

The most important process for the destruction of microorganisms is disinfection. In the U.S., the most common disinfectant for both water and wastewater is chlorine. Ozone and UV light are other prominent disinfectants used at wastewater treatment plants. Factors that should be considered when evaluating disinfection alternatives include disinfection effectiveness and reliability, capital costs, operating and maintenance costs, practicality (e.g., ease of transport and storage or onsite generation, ease of application and control, flexibility, complexity, and safety), and potential adverse effects. Examples of adverse effects include toxicity to aquatic life or formation of toxic or carcinogenic substances. The predominant advantages and disadvantages of disinfection alternatives are well known and have been summarized by the EPA in their Wastewater Technology Fact Sheets on Ultraviolet Disinfection (September 1999), Ozone Disinfection (September 1999), and Chlorine Disinfection (September 1999), Design Manual entitled, "Municipal Wastewater Disinfection" and Water Environment Federation (WEF) Manual of Practice FD-10 (1996).

The efficiency of chlorine disinfection depends on the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of chlorinating species, and the nature and concentration of the organisms to be destroyed. In general, bacteria are less resistant to chlorine than viruses, which in turn, are less resistant than parasite ova and cysts.

Figure 3-10. Generalized Flow Sheet for Wastewater Treatment



Source: Adapted from Pettygrove and Asano, 1985

The chlorine dosage required to disinfect wastewater to any desired level is greatly influenced by the constituents present in the wastewater. Some of the interfering substances are:

- Organic constituents, which consume the disinfectant
- Particulate matter, which protects microorganisms from the action of the disinfectant
- Ammonia, which reacts with chlorine to form chloramines, a much less effective disinfectant species than free chlorine

In practice, the amount of chlorine added is determined empirically, based on desired residual and effluent quality. Chlorine, which in low concentrations is toxic to many aquatic organisms, is easily controlled in reclaimed water by dechlorination, typically with sulfur dioxide.

Chlorine is a regulated substance with a threshold quantity of 2,500 pounds (1130 kg). If a chlorine system contains a larger quantity of chlorine than the threshold quantity, a Risk Management Plan (RMP) must be completed. Two main factors of the RMP that prompt many municipalities to switch to alternative disinfection systems are: (1) the RMP is not a one-time requirement, it has to be updated every 5 years; and (2) concern over public reaction to the RMP, which requires that a "kill zone" be geographically defined around the treatment facility. This "kill zone" may include residential areas near the treatment plant. Thus, RMP requirements and decreasing chemical costs for commercial grade sodium hypochlorite have resulted in many municipalities switching from chlorine gas to commercial grade sodium hypochlorite to provide disinfection of their wastewater.

Ozone (O_3), is a powerful disinfecting agent and chemical oxidant in both inorganic and organic reactions. Due to the instability of ozone, it must be generated onsite from air or oxygen carrier gas. Ozone destroys bacteria and viruses by means of rapid oxidation of the protein mass, and disinfection is achieved in a matter of minutes. Ozone is a highly effective disinfectant for advanced wastewater treatment plant effluent, removing color, and contributing dissolved oxygen. Some disadvantages to using ozone for disinfection are: (1) the use of ozone is relatively expensive and energy intensive, (2) ozone systems are more complex to operate and maintain than chlorine systems, and (3) ozone does not maintain a residual in water.

UV is a physical disinfecting agent. Radiation at a wavelength of 254 mm penetrates the cell wall and is absorbed by the cellular nucleic acids. This can prevent replication by eliminating the organism's ability to cause infection. UV radiation is frequently used for wastewater treatment plants that discharge to surface waters to avoid the need for dechlorination prior to release of the effluent. UV is receiving increasing attention as a means of disinfecting reclaimed water for the following reasons: (1) UV may be less expensive than disinfecting with chlorine, (2) UV is safer to use than chlorine gas, (3) UV does not result in the formation of chlorinated hydrocarbons, and (4) UV is effective against *Cryptosporidium* and *Giardia*, while chlorine is not.

The effectiveness of UV radiation as a disinfectant (where fecal coliform limits are on the order of 200/100 ml) has been well established, and is used at small- to medium-sized wastewater treatment plants throughout the U.S. Today, UV radiation to achieve high-level disinfection for reuse operations is acceptable in some states. In recognition of the possible harmful effects of chlorine, the Florida Department of Environmental Protection (FDEP) encourages the use of alternative disinfection methods (FDEP, 1996). The WERF published a final report entitled, "Disinfection Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance." This report provides a broad-based discussion of the advantages and disadvantages of chlorine and UV, using an empirical model to determine the UV dose required for various levels of coliform inactivation. The report also includes cost information and a comparison of chlorination/dechlorination and UV systems (WERF, 1995). Studies in San Francisco, California, indicated that suspended solids play a major role in UV efficiency. This included the finding that, as the concentration of particles 7 mm and larger increase, the ability to achieve acceptable disinfection with UV decreases. Thus, filtration must be optimized to manage this problem (Jolis *et al.,* 1996).

The goal of UV disinfection in reuse applications typically is to inactivate 99.999 percent or more of the target pathogens (Swift *et al.,* 2002). The 2000 National Water Research Institute (NWRI) guidelines provide detailed guidance for the design of UV systems that will achieve high-level disinfection to meet some state standards for public access reuse. The 2000 NWRI guidelines also include a well-defined testing protocol and validation test as a means to provide reasonable assurance that the domestic wastewater treatment facility can meet the high-level disinfection criteria (NWRI and AWWA, 2000).

The Bethune Point WWTP in Daytona Beach, Florida, is the largest UV disinfection system in the state of Florida designed for reuse operations. This facility is also the first public access reuse facility in Florida with UV disinfection to be permitted for unrestricted public access (Elefritz, 2002). Placed into service in December 1999, the Bethune Point WWTP UV disinfection system is a medium pressure/high intensity system designed for a dose of 80mW-s/cm^2 (800 J/m^2) to achieve the high-level disinfection standard. The City of Henderson, Nevada water reclamation facility conducted collimated beam studies of a low pressure/high intensity UV disinfection system. The studies demonstrated that the disinfection goal of 20 fecal coliforms per 100 ml was achievable with a minimum UV dose of 200 J/m^2 (Smith and Brown, 2002).

Other disinfectants, such as onsite chlorine generation, gamma radiation, bromine, iodine, and hydrogen peroxide, have been considered for the disinfection of wastewater. These disinfectants are not generally used because of economical, technical, operational, or disinfection efficiency considerations.

3.4.2.2 Advanced Wastewater Treatment

Advanced wastewater treatment processes are those beyond traditional secondary treatment. These processes are generally used when high quality reclaimed water is needed. Examples include: (1) urban landscaping, (2) food crops eaten raw, (3) contact recreation, and (4) many industrial applications. Individual unit processes capable of removing the constituents of concern are shown in **Figure 3-11**.

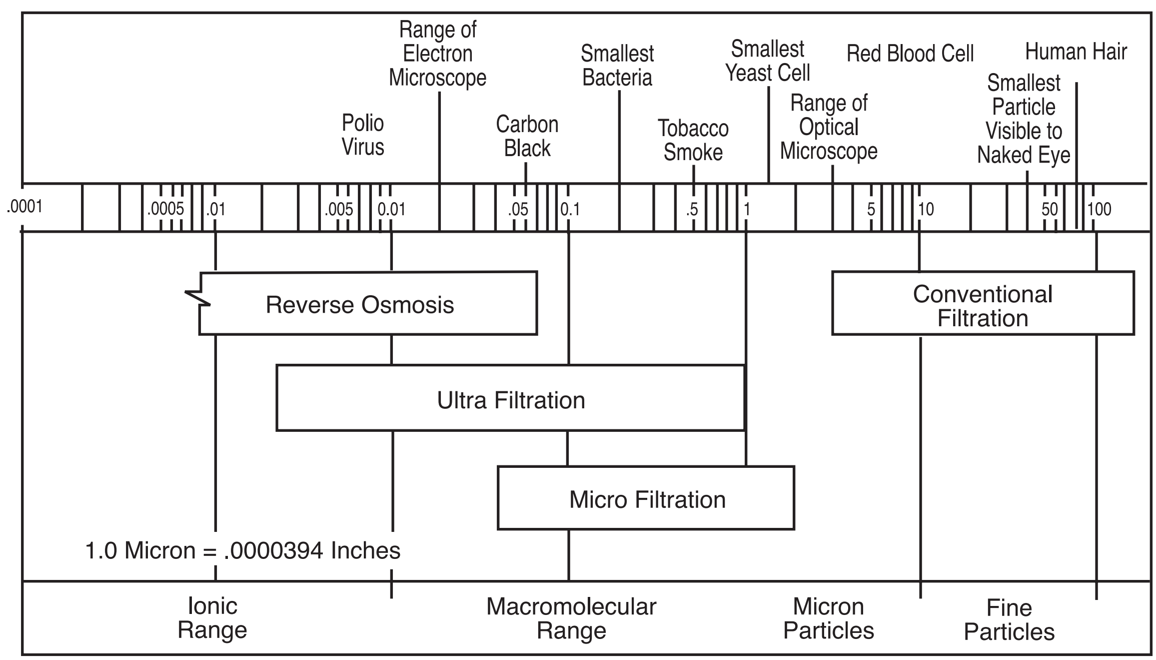
The principal advanced wastewater treatment processes for water reclamation are:

- Filtration – Filtration is a common treatment process used to remove particulate matter prior to disinfection. Filtration involves the passing of wastewater through a bed of granular media or filter cloth, which retain the solids. Typical media include sand, anthracite, and garnet. Removal efficiencies can be improved through the addition of certain polymers and coagulants.

- UV Treatment of NDMA – UV Treatment, considered an Advanced Oxidation Technology (AOT), is the only proven treatment to effectively reduce NDMA. The adsorption of ultraviolet light, even the UV portion of sunlight, by NDMA causes the molecule to disassociate into harmless fragments (Nagel *et al.*, 2001). A study done at West Basin Municipal Water District in Carson, California proved NDMA concentrations were reduced by both low and medium pressure UV (Nagel *et al.*, 2001).

- Nitrification – Nitrification is the term generally given to any wastewater treatment process that biologically converts ammonia nitrogen sequentially to ni-

Figure 3-11. Particle Size Separation Comparison Chart



Adapted from AWWA, 1990

trite nitrogen and nitrate nitrogen. Nitrification does not remove significant amounts of nitrogen from the effluent; it only converts nitrogen into another chemical form. Nitrification can be achieved in many suspended and attached growth treatment processes when the processes are designed to foster the growth of nitrifying bacteria. In the traditional activated sludge process, this is accomplished by designing the process to operate at a solids retention time (SRT) that is long enough to prevent slow-growing nitrifying bacteria from being wasted out of the system. Nitrification will also occur in trickling filters that operate at low BOD/TKN ratios either in combination with BOD removal, or as a separate advanced treatment process following any type of secondary treatment. A well-designed and -operated nitrification process will produce an effluent containing 1.0 mg/l or less of ammonia nitrogen.

- Denitrification – Denitrification is any wastewater treatment method that completely removes total nitrogen. As with ammonia removal, denitrification is usually best achieved biologically, in which case it must be preceded by nitrification. In biological denitrification, nitrate nitrogen is used by a variety of heterotrophic bacteria as the terminal electron acceptor in the absence of dissolved oxygen. In the process, the nitrate nitrogen is converted to nitrogen gas, which escapes to the atmosphere. The bacteria in these processes also require a carbonaceous food source. Denitrification can be achieved using many alternative treatment processes including variations of many common suspended growth and some attached growth treatment processes, provided that the processes are designed to create the proper microbial environment. Biological denitrification processes can be designed to achieve effluent nitrogen concentrations between 2.0 and 12 mg/l of nitrate nitrogen.

- Phosphorus Removal – Phosphorus can be removed from wastewater through chemical or biological methods, or a combination. The choice of methods will depend on site-specific conditions, including the amount of phosphorus to be removed and the desired effluent phosphorus concentration. Chemical phosphorus removal is achieved by precipitating the phosphorus from solution through the addition of iron, aluminum, or calcium salts. Biological phosphorus removal relies on the culturing of bacteria that will store excess amounts of phosphorus when exposed to anaerobic conditions, followed by aerobic conditions in the treatment process. In both cases, the phosphorus is removed from the treatment process with the waste sludge. Chemical phosphorus removal can attain effluent orthophosphorus concentrations of less than 0.1 mg/l, while biological phosphorus removal will usually produce an effluent phosphorus concentration between 1.0 and 2.0 mg/l.

- Coagulation-Sedimentation – Chemical coagulation with lime, alum, or ferric chloride followed by sedimentation removes SS, heavy metals, trace substances, phosphorus, and turbidity.

- Carbon Adsorption – One effective advanced wastewater treatment process for removing biodegradable and refractory organic constituents is granular activated carbon (GAC). Carbon adsorption can reduce the levels of synthetic organic chemicals in secondary effluent by 75 to 85 percent. The basic mechanism of removal is by adsorption of the organic compounds onto the carbon. Carbon adsorption proceeded by conventional secondary treatment and filtration can produce an effluent with a BOD of 0.1 to 5.0 mg/l, a COD of 3 to 25 mg/l, and a TOC of 1 to 6 mg/l. Carbon adsorption treatment will also remove several metal ions, particularly cadmium, hexavalent chromium, silver, and selenium. Activated carbon has been used to remove uncharged species, such as arsenic and antimony, from an acidic stream. Carbon adsorption has also been reported as an effective means of removing endocrine disrupting compounds (Hunter and Long, 2002).

- Membrane Processes – In recent years, the same factors that favor the use of membranes for potable water treatment (increasing demand, decreasing source water quality, and more stringent regulatory standards) are influencing their use in treating wastewaters prior to reuse. Improvements in membrane technologies which separate suspended solids, dissolved compounds, and human pathogens (protozoan cysts, bacteria and viruses) from reclaimed water have inspired greater confidence in the use of reclaimed water for purposes which include both direct and indirect human contact.

  Membrane filters became commercially available in 1927 from the Sartorius Company in Germany. Until the mid-1940s, these filters were used primarily to remove microorganisms and particles from air and water. The first viable reverse osmosis membrane was developed in 1960 by researchers at the University of California at Los Angeles (UCLA). The first commercial reverse osmosis (RO) treatment plant went into service in 1965 in Coalinga, California. The use of membrane filtration systems was initially limited to specialized applications including industrial separation processes and seawater desalination. By the 1980s, membrane technology was well established.

For many years, membranes were not used for wastewater treatment due to rapid fouling. Prior to 1990, there were a few notable exceptions, including a highly publicized 5-mgd RO system at the Water Factory 21 reclamation plant in Orange County, California. This system went into service in 1975. The plant used cellulose acetate membranes with lime clarification and multi-media filtration for pretreatment prior to the RO system. Another notable exception was a 3.3-mgd (12 x 10^3-m^3/d) Petromin plant in Riyadh, Saudia Arabia.

The large-scale use of membranes for wastewater reclamation did not become feasible until the1980s, when the Australian firm, Memtec, developed a hollow fiber microfiltration membrane system with an air backwash that could provide sustainable operation for wastewater. The Orange County Water District (California) began pilot testing in 1992 to investigate this new microfiltration system as pretreatment for reverse osmosis. The use of this new microfiltration system, followed by thin film composite RO membranes, proved to be a tremendous improvement over the then-conventional system of lime clarification, sand filtration, and cellulose acetate membranes. Between 1994 and 2000, over half a dozen new dual membrane water reclamation systems were constructed in California and Arizona.

Pressure-driven membrane treatment systems are broadly categorized by the size particles rejected by the membrane, or by the molecular weight cut off (MWCO). These classifications include:

Microfiltration (MF)	0.1 μm	or	500, 000 MWCO
Ultrafiltration (UF)	0.01 μm	or	20,000 MWCO
Nanofiltration (NF)	0.001 μm	or	200 MWCO
Reverse Osmosis (RO)	0.0001 μm	or	< 100 MWCO

Figure 3-11 shows a particle size separation comparison chart for conventional filtration, microfiltration, ultrafiltration, and reverse osmosis. **Tables 3-13a** and **3-13b** contain microfiltration and reverse osmosis removal data (Metcalf and Eddy, 2002).

MF systems are used to remove relatively large suspended particles including particulates, large colloids, and oil. This includes providing about 3 to 6 log (99.9 percent to 99.9999 percent) removal of bacteria. In wastewater treatment, MF systems can be used to replace secondary clarifiers and more conventional (sand) filters following biological treatment. UF membranes have smaller pore sizes than MF membranes and will provide complete removal of bacteria and protozoan cysts, and 4 to 6 log removal for viruses. Otherwise, UF membranes perform the same basic functions in wastewater applications as MF membranes. NF and RO, while retaining smaller particles including molecules and ions, require higher driving pressures, higher levels of pretreatment (prefiltration), and typically operate at lower recovery rates.

For wastewater treatment, the main emphasis has been on MF, UF, and RO membranes. MF and UF have the ability to remove biological contaminants (e.g., bacteria and viruses), and to reduce fouling on downstream reverse osmosis membranes. NF or RO systems are needed where the removal of colloidal and/or dissolved materials is required.

Membrane Bioreactors (MBRs)

MBRs typically consist of UF or MF membranes. These membranes are used to replace conventional gravity clarifiers, and return activated sludge systems in conventional activated sludge biological treatment systems. The membranes can be immersed directly into the aeration tanks, or the mixed liquor can be pumped to external pressure-driven membrane units. MBRs exhibit a number of unique advantages:

- Sludge settling characteristics no longer affect final effluent quality. Biological processes can be operated at much higher suspended solids concentrations and thereby provide greater treatment capacity per unit volume.
- MF and UF membranes provide nearly complete removal of protozoan cysts, suspended solids, and bacteria, as well as partial removal of viruses. In addition to removing suspended solids, UF membranes can retain large organic molecules, improving the biodegradation of otherwise resistant compounds such as grease or emulsified oils.
- Longer sludge ages (as long as 30 to 45 days) are possible, improving the biodegradation of resistant compounds and improving nitrification performance under adverse conditions (such as low temperature).
- Wasting occurs directly from the aeration basin, improving process control.
- Submerged MBR systems are well suited to upgrade existing systems with minimum new construction required and low impact to ongoing operations.

Table 3-13a. Microfiltration Removal Performance Data

Constituent	MF Influent (mg/l)	MF Effluent (mg/l)	Average Reduction (%)	Reduction Reported in Literature (%)
TOC	10-31	9-16	57	45-65
BOD	11-32	<2-9.9	86	75-90
COD	24-150	16-53	76	70-85
TSS	8-46	<0.5	97	95-98
TDS	498-622	498-622	0	0-2
NH_3-N	21-42	20-35	7	5-15
NO_3-N	<1-5	<1-5	0	0-2
PO_4^-	6-8	6-8	0	0-2
SO_4^{2-}	90-120	90-120	0	0-1
Cl^-	93-115	93-115	0	0-1
Turbidity	2-50 NTU	0.03-0.08 NTU	>99	---

[1] Data collected from the Dublin San Ramon Sanitary District for the period from April 2000 through December, 2000.

[2] Typical flux rate during test period was 1600 l/m^2·d.

Adapted from: Metcalf and Eddy, 2002

Table 3-13b. Reverse Osmosis Performance Data

Constituent	RO Influent (mg/l)	RO Effluent (mg/l)	Average Reduction (%)	Reduction Reported in Literature (%)
TOC	9-16	<0.5	>94	85-95
BOD	<2-9.9	<2	>40	30-60
COD	16-53	<2	>91	85-95
TSS	<0.5	~0	>99	95-100
TDS	498-622	9-19	---	90-98
NH_3-N	20-35	1-3	96	90-98
NO_3-N	<1-5	0.08-3.2	96	65-85
PO_4^-	8-Jun	0.1-1	~99	95-99
SO_4^{2-}	90-120	<0.5-0.7	99	95-99
Cl^-	93-115	0.9-5.0	97	90-98
Turbidity	0.03-0.08 NTU	0.03 NTU	50	40-80

[1] Data collected from the Dublin San Ramon Sanitary District for the period from April 1999 through December, 1999.

[2] Typical flux rate during test period was 348 l/m^2·d.

Adapted from: Metcalf and Eddy, 2002

Submerged membrane assemblies, either MF or UF, are typically composed of bundles of hollow fiber or flat sheets of microporous membranes. Filtrate is drawn through the membrane assemblies by means of a vacuum applied to the product side of the membrane. Turbulence on the exterior (feed side) is maintained by diffused aeration to reduce fouling.

Low-pressure membrane filtration (MF or UF) can be used following secondary clarification to provide a higher degree of solids removal. Operating in a conventional (pressurized) flow pattern, clarified effluent is further treated to remove particulate material (MF) or colloidal material (UF). Typical operating pressures range from 20 to 100 psi (100 to 700 KPa), and reject flows range from 2 to 50 percent. MF and UF membranes can be used to pre-treat flow prior to NF or RO treatment.

Higher-pressure NF and RO systems are used to remove dissolved organic and inorganic compounds. The smaller pore size (lower MWCO) results in higher quality product water, which may meet primary and secondary drinking water standards. The higher rates of rejection also result in increasing problems for disposing of the concentrate streams.

- Other Processes – Other advanced wastewater treatment processes of constituent removal include ammonia stripping, breakpoint chlorination for ammonia removal, and selective ion exchange for nitrogen removal.

3.4.3 Reliability in Treatment

A high standard of reliability, similar to water treatment plants, is required at wastewater reclamation plants. Because there is potential for harm (i.e., in the event that improperly treated reclaimed water is delivered to the use area), water reuse requires strict conformance to all applicable water quality parameters. The need for reclamation facilities to reliably and consistently produce and distribute reclaimed water of adequate quality and quantity is essential and dictates that careful attention be given to reliability features during the design, construction, and operation of the facilities.

A number of fallible elements combine to make up an operating water reclamation system. These include the power supply, individual treatment units, mechanical equipment, the maintenance program, and the operating personnel. An array of design features and non-design provisions can be employed to improve the reliability of the separate elements and the system as a whole. Back-up systems are important in maintaining reliability in the event of failure of vital components. Particularly critical units include the disinfection system, power supply, and various treatment unit processes.

For reclaimed water production, EPA Class I reliability is recommended as a minimum criteria. Class I reliability requires redundant facilities to prevent treatment upsets during power and equipment failures, flooding, peak loads, and maintenance shutdowns. Reliability for water reuse should also consider:

- Operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems

- Instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions

- A comprehensive quality assurance program to ensure accurate sampling and laboratory analysis protocol

- Adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or alternative disposal

- Supplemental storage and/or water supply to ensure that the supply can match user demands

- A strict industrial pretreatment program and strong enforcement of sewer use ordinances to prevent illicit dumping into the collection system of hazardous materials or other materials that may interfere with the intended use of the reclaimed water

- A comprehensive operating protocol that defines the responsibilities and duties of the operations staff to ensure the reliable production and delivery of reclaimed water

Many states have incorporated procedures and practices into their reuse rules and guidelines to enhance the reliability of reclaimed water systems. Florida requires the producer of reclaimed water to develop a detailed operating protocol for all public access systems. This protocol must identify critical monitoring and control equipment, set points for chlorine and turbidity, actions to be taken in the event of a failure to achieve these limits, and procedures to clear the substandard water and return to normal operations (FAC 62-610). Washington is in the process of developing Water Reclamation Facilities Reliability Assessment Guidance, which includes an alarm and reliability checklist.

3.4.3.1 EPA Guidelines for Reliability

More than 30 years ago, before the Federal Water Quality Administration evolved into the EPA, it recognized the importance of treatment reliability, issuing guidelines entitled, “Federal Guidelines: Design, Operation and Maintenance of Waste Water Treatment Facilities” (Federal Water Quality Administration, 1970). These guidelines provided an identification and description of various reliability provisions and included the following concepts or principles regarding treatment plant reliability:

- All water pollution control facilities should be planned and designed to provide for maximum reliability at all times.

- Each facility should be capable of operating satisfactorily during power failures, flooding, peak loads, equipment failure, and maintenance shutdowns.

- Such reliability can be obtained through the use of various design techniques that will result in a facility that is virtually "fail-safe" (Federal Water Quality Administration, 1970).

The following points highlight more specific subjects for consideration in preparing final construction plans and specifications to help accomplish the above principles:

- Duplicate dual feed sources of electric power

- Standby onsite power for essential plant elements

- Multiple process units and equipment

- Holding tanks or basins to provide for emergency storage of overflow and adequate pump-back facilities

- Flexibility of piping and pumping facilities to permit rerouting of flows under emergency conditions

- Provision for emergency storage or disposal of sludge (Federal Water Quality Administration, 1970)

The non-design reliability features in the federal guidelines include provisions for qualified personnel, an effective monitoring program, and an effective maintenance and process control program. In addition to plans and specifications, the guidelines specify submission of a preliminary project planning and engineering report, which will clearly indicate compliance with the guideline principles.

In summary, the federal guidelines identify the following 8 design principles and 4 other significant factors that appear to be appropriate to consider for reuse operations:

<u>Design Factors</u>

Duplicate power sources

Standby power

Multiple units and equipment

Emergency storage

Piping and pumping flexibility

Dual chlorination systems

Automatic residual control

Automatic alarms

<u>Other Factors</u>

Engineering report

Qualified personnel

Effective monitoring program

Effective maintenance and process control program

In 1974, EPA subsequently published a document entitled, "Design Requirements for Mechanical, Electric, and Fluid Systems and Component Reliability" (U.S. EPA, 1974). While the purpose of that publication was to provide reliability design criteria for wastewater treatment facilities seeking federal financial assistance under PL 92-500, the criteria are useful for the design and operation of all wastewater treatment plants. These requirements established minimum standards of reliability for wastewater treatment facilities. Other important reliability design features include on-line monitoring (e.g., turbidimeters and chlorine residual analyzers, and chemical feed facilities.

Table 3-14 presents a summary of the equipment requirements under the EPA guidelines for Class I reliability treatment facilities.

As shown in Table 3-14, the integrity of the treatment system is enhanced by providing redundant, or oversized unit processes. This reliability level was originally specified for treatment plants discharging into water bodies that could be permanently or unacceptably damaged by improperly treated effluent. Locations where Class I facilities might be necessary are indicated as facilities discharging near drinking water reservoirs, into shellfish waters, or in proximity to areas used for water contact sports (U.S. EPA, 1974). While over 30 years old, the definition of Class I Reliability given in Table 3-14 is still referenced in the regulations of many states as the minimum level of reliability required for water reclamation projects.

Table 3-14. Summary of Class I Reliability Requirements

Unit	Class I Requirement
Mechanically-Cleaned Bar Screen	A back-up bar screen shall be provided (may be manually cleaned).
Pumps	A back-up pump shall be provided for each set of pumps which perform the same function. Design flow will be maintained with any 1 pump out of service.
Comminution Facilities	If comminution is provided, an overflow bypass with bar screen shall be provided.
Primary Sedimentation Basins	There shall be sufficient capacity such that a design flow capacity of 50 % of the total capacity will be maintained with the largest unit out of service.
Filters	There shall be a sufficient number of units of a size such that a design capacity of at least 75 % of the total flow will be maintained with 1 unit out of service.
Aeration Basins	At least 2 basins of equal volume will be provided.
Mechanical Aerator	At least 2 mechanical aerators shall be provided. Design oxygen transfer will be maintained with 1 unit out of service.
Chemical Flash Mixer	At least 2 basins or a back-up means of mixing chemicals separate from the basins shall be provided.
Final Sedimentation Basins	There shall be a sufficient number of units of a size such that 75% of the design capacity will be maintained with the largest unit out of service.
Flocculation Basins	At least 2 basins shall be provided.
Disinfectant Contact Basins	There shall be sufficient number of units of a size such that the capacity of 50% of the total design flow may be treated with the largest unit out of service.

Source: Adapted from U.S. Environmental Protection Agency, 1974

3.4.3.2 Additional Requirements for Reuse Applications

Different degrees of hazard are posed by process failures. From a public health standpoint, it is logical that a greater assurance of reliability should be required for a system producing reclaimed water for uses where direct or indirect human contact with the water is likely, than for water produced for uses where the possibility of contact is remote. Similarly, where specific constituents in reclaimed water may affect the acceptability of the water for any use (e.g., industrial process water), reliability directed at those constituents is important. Standby units or multiple units should be encouraged for the major treatment elements at all reclamation facilities. For small installations, the cost may be prohibitive and provision for emergency storage or disposal is a suitable alternative.

a. Piping and Pumping Flexibility

Process piping, equipment arrangements, and unit structures should provide for efficiency, ease of operation and maintenance, and maximum flexibility of operation. Flexibility plans should permit the necessary degree of treatment to be obtained under varying conditions. All aspects of plant design should allow for routine maintenance of treatment units without deterioration of the plant effluent.

No pipes or pumps should be installed that would circumvent critical treatment processes and possibly allow inadequately treated effluent to enter the reclaimed water distribution system. The facility should be capable of operating during power failures, peak loads, equipment failures, treatment plant upsets, and maintenance shutdowns. In some cases, it may be necessary to divert the wastewater to emergency storage facilities or discharge the wastewater to approved, non-reuse areas. During power failures or in the case of an equipment failure, standby portable diesel-driven pumps can also be used.

b. Emergency Storage or Disposal

The term "emergency storage or disposal" means to provide for the containment or alternative treatment and disposal of reclaimed water whenever the quality is not suitable for use. It refers to something other than normal operational or seasonal storage (e.g., storage that may be used to hold reclaimed water during wet weather times until it is needed for use). Provisions for emergency storage or disposal may be considered to be a basic reliability provision for some reclamation facilities. Where such provisions exist, they may substitute for multiple or standby units and other specific features.

Provisions for emergency storage or disposal may include:

- Holding ponds or tanks
- Approved alternative disposal locations such as percolation areas, evaporation-percolation ponds, or spray disposal areas
- Deep injection wells
- Pond systems having an approved discharge to receiving waters or discharge to a reclaimed water use area for which lower quality water is acceptable
- Provisions to return the wastewater to a sewer for subsequent treatment and disposal at the reclamation or other facility
- Any other facility reserved for the purpose of emergency storage or disposal of untreated or partially-treated wastewater

Automatically-actuated emergency or disposal provisions should include all of the necessary sensors, instruments, valves, and other devices to enable fully automatic diversion of the wastewater in the event of failure of a treatment process, and a manual reset to prevent automatic restart until the failure is corrected. For either manual or automatic diversion, all of the equipment other than the pump-back equipment should either be independent of the normal power source or provided with a standby power source. Irvine Ranch Water District in California automatically diverts its effluent to a pond when it exceeds a turbidity of 2 NTU. The water is then recirculated into the reclamation plant influent.

Where emergency storage is to be used as a reliability feature, storage capacity is an important consideration. This capacity should be based on estimates of how long it will take to return the facilities to normal operations and the penalties (regulatory or otherwise) associated with loss of treatment and discontinuation of reclaimed water service.

c. Alarms

Alarm systems should be installed at all water reclamation plants, particularly at plants that do not receive full-time attention from trained operators. Minimum instrumentation should consist of alarms at critical treatment units to alert an operator of a malfunction. This concept requires that the plant either be constantly attended, or that an operator be on call whenever the reclamation plant is in operation. In the latter case, a remote sounding device would be needed. If conditions are such that rapid attention to failures cannot be assured, automatically actuated emergency control mechanisms should be installed and maintained. Supervisory control and data acquisition (SCADA) systems may be employed to accomplish this objective, so long as information is made available to locations that are staffed when operators are not on site at the remote reclaimed water facilities. If a critical process were to fail, the condition may go unnoticed for an extended time period, and unsatisfactory reclaimed water would be produced for use. An alarm system will effectively warn of an interruption in treatment.

Requirements for warning systems may specify the measurement to be used as the control in determining a unit failure (e.g., dissolved oxygen) in an aeration chamber or the requirements could be more general in nature, merely specifying the units or processes that should be included in a warning system. The latter approach appears more desirable because it allows for more flexibility in the design. Alarms could be actuated in various ways, such as failure of power, high water level, failure of pumps or blowers, loss of dissolved oxygen, loss of coagulant feed, high head loss on filters, high effluent turbidity, or loss of disinfection.

In addition to the alarm system, it is critical to have a means available to take corrective action for each situation, which has caused the alarm to be activated. As noted above, provisions must be available to otherwise treat, store, or dispose of the wastewater until the corrections have been made. Alternative or supplemental features for different situations might include an automatic switchover mechanism to emergency power and a self-starting generator, or an automatic diversion mechanism which discharges wastewater from the various treatment units to emergency storage or disposal.

d. Instrumentation and Control

Major considerations in developing an instrumentation/ control system for a reclamation facility include:

- Ability to analyze appropriate parameters
- Ability to maintain, calibrate, and verify accuracy of on-line instruments
- Monitoring and control of treatment process performance
- Monitoring and control of reclaimed water distribution
- Methods of providing reliability
- Operator interface and system maintenance

The potential uses of the reclaimed water determine the degree of instrument sophistication and operator attention required in a water reuse system. For example, health risks may be insignificant for reclaimed water used for non-food crop irrigation. On the other hand, if wastewater is being treated for indirect potable reuse via groundwater recharge, risks are potentially high. Consequently, the instruments must be highly sensitive so that even minor discrepancies in water quality are detected rapidly.

Selection of monitoring instrumentation is governed by the following factors:

- Sensitivity
- Accuracy
- Effects of interferences
- Frequency of analysis and detection
- Laboratory or field application
- Analysis time
- Sampling limitations
- Laboratory requirements
- Acceptability of methods
- Physical location
- Ability to provide service and
- Reliability

Source: WPCF, 1989

Each water reclamation plant is unique, with its own requirements for an integrated monitoring and control instrumentation system. The process of selecting monitoring instrumentation should address aspects such as frequency of reporting, parameters to be measured, sample point locations, sensing techniques, future requirements, availability of trained staff, frequency of maintenance, availability of spare parts, and instrument reliability (WPCF, 1989). Such systems should be designed to detect operational problems during both routine and emergency operations. If an operating problem arises, activation of a signal or alarm permits personnel to correct the problem before an undesirable situation is created.

System control methods should provide for varying degrees of manual and automatic operation. Functions of control include the maintenance of operating parameters within preset limits, sequencing of physical operations in response to operational commands and modes, and automatic adjustment of parameters to compensate for variations in quality or operating efficiency.

System controls may be manual, automated, or a combination of manual and automated systems. For manual control, operations staff members are required to physically carry out all work tasks, such as closing and opening valves and starting and stopping pumps. For automated control, no operator input is required except for the initial input of operating parameters into the control system. In an automated control system, the system automatically performs operations such as the closing and opening of valves and the starting and stopping of pumps. These automated operations can be accomplished in a predefined sequence and timeframe and can also be initiated by a measured parameter.

Automatic controls can vary from simple float switches that start and stop pumps to highly sophisticated computer systems that gather data from numerous sources, compare the data to predefined parameters, and initiate actions in order to maintain system performance within required criteria. For example, in the backwashing of a filter, instrumentation that monitors head loss across a filter signals the automated control system that a predefined head loss value has been exceeded. The control system, in turn, initiates the backwashing sequence through the opening of valves and starting of pumps. A simple, but effective, means of maintaining control in the event of a power failure might include a judicious selection of how control valves respond to loss of power. For example, in a reuse system with a pair of control valves routing water either to customers or to a reject location, it is reasonable to expect that the valve to the customers should fail to the closed position, while the valve to reject would fail to the open position.

3.4.3.3 Operator Training and Competence

Regardless of the automation built into a plant, mechanical equipment is subject to breakdown, and qualified, well-trained operators are essential to ensure that the reclaimed water produced will be acceptable for its intended use. The facilities operation should be based on detailed process control with recording and monitoring facilities, a strict preventive maintenance schedule, and standard operating procedure contingency plans all structured to provide reliable product water quality.

The plant operator is considered to be the most critical reliability factor in the wastewater treatment system. All available mechanical reliability devices and the best possible plant design are to no avail if the operator is not capable and conscientious. Three operations personnel considerations influence reliability of treatment: operator attendance, operator competence, and operator training. The knowledge, skills, and abilities that an operator must possess varies, depending on the complexity of the plant. Most regulatory agencies require operator certification as a reasonable means to expect competent operation. Frequent training via continuing education courses or other means enhances operator competence.

Actions of the system operator have the potential to adversely affect water quality and public perception of the reclaimed water system. Therefore, a knowledgeable, attentive operator is critical to avoid potential threats to water quality. Consideration should be given to provide special training and certification for reclaimed water operations staff.

3.4.3.4 Quality Assurance in Monitoring

Quality assurance (QA) in monitoring of a reclamation program includes: (1) selecting the appropriate parameters to monitor, and (2) handling the necessary sampling and analysis in an acceptable manner. Sampling techniques, frequency, and location are critical elements of monitoring and quality assurance. Standard procedures for sample analysis may be found in the following references:

- *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, 1989)
- *Handbook for Analytical Quality Control in Water and Wastewater Laboratories* (U.S. EPA, 1979a)
- *Methods for Chemical Analysis of Water and Wastes* (U.S. EPA, 1983)
- *Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater* (U.S. EPA, 1996)
- *Handbook for Sampling and Sample Preservation of Water and Wastewater* (U.S. EPA, 1982)

Typically, the QA plan associated with sampling and analysis is a defined protocol that sets forth data quality objectives and the means to develop quality control data. This serves to quantify precision, bias, and other reliability factors in a monitoring program. Strict adherence to written procedures ensures that the results are comparable, and that the level of uncertainty is verifiable.

Quality assurance/quality control (QA/QC) plans and procedures are well documented in referenced texts. QA/QC measures should be dictated by the severity of the consequences of acting on the “wrong answer” or on an “uncertain” answer. QA/QC procedures are often dictated by regulatory agencies, and do constitute necessary operating overhead. For reuse projects, this overhead may be greater than for wastewater treatment and disposal.

Sampling parameters required for reclamation extend beyond those common to wastewater treatment. For example, turbidity measurements are sometimes required for reclamation, but not for wastewater treatment and disposal. Monitoring for chlorides may be necessary for reuse in coastal communities.

Adequate record keeping of reclaimed water system operations is essential to the overall monitoring program. Many facilities find it reasonable and compatible with their usual practice and requirements to include routine reporting of plant operations and immediate notification of emergency conditions.

3.5 Seasonal Storage Requirements

Managing and allocating reclaimed water supplies may be significantly different from the management of traditional sources of water. Traditionally, a water utility drawing from groundwater or surface impoundments uses the resource as a source and as a storage facility. If the entire yield of the source is not required, the water is simply left for use at a later date. Yet in the case of reuse, reclaimed water is continuously generated, and what cannot be used immediately must be stored or disposed of in some manner.

Depending on the volume and pattern of projected reuse demands, seasonal surface storage requirements may become a significant design consideration and have a substantial impact on the capital cost of the system. Seasonal storage systems will also impact operational expenses. This is particularly true if the quality of the water is degraded in storage by algae growth and requires re-treatment to maintain the desired or required water quality. Pilot studies in California investigated the use of clarifiers with coagulation and continuous backwash filtration versus the use of dissolved air flotation with clarification and filtration. The estimated present worth costs of these 2 strategies for treating reclaimed water returned from storage ponds were calculated at \$1.92/gal (\$0.51/l) and \$2.17/gal (\$0.57/l), respectively (Fraser and Pan, 1998).

The need for seasonal storage in reclaimed water programs generally results from 1 of 2 requirements. First, storage may be required during periods of low demand for subsequent use during peak demand periods. Second, storage may be required to reduce or eliminate the discharge of excess reclaimed water into surface water or groundwater. These 2 needs for storage are not mutually exclusive, but different parameters are considered in developing an appropriate design for each one. In fact, projects where both water conservation and effluent disposal are important are more likely to be implemented than those with a single driver. Drivers for the creation of an urban reuse system in Tampa, Florida included water conservation as well as the fact that any reclaimed water diverted to beneficial reuse helped the City to meet its obligations to reduce nitrogen loadings to area surface waters (Grosh *et al.,* 2002). At the outset, it must be recognized that the use of traditional storage methods with finite capacities (e.g., tanks, ponds, and reservoirs) must be very large in comparison to the design flows in order to provide 100 percent equalization of seasonal supplies and demands. With an average flow of 18 mgd (68 x 10^3 m^3/d) and a storage volume of 1,600 million gallons (6 x 10^6 m^3), the City of Santa Rosa, California, still required a seasonal discharge to surface water to operate successfully (Cort *et al.,* 1998). After attempting to operate a 3.0 mgd (11 x 10^3 m^3/d) agricultural reuse system with 100 mg (0.4 x 10^6 m^3) of storage, Brevard County, Florida, decided to add manmade wetlands with a permitted surface water discharge as part of its wet weather management system (Martens *et al.,* 1998).

ASR of reclaimed water involves the injection of reclaimed water into a subsurface formation for storage, and recovery for beneficial use at a later time. ASR can be an effective and environmentally-sound approach by providing storage for reclaimed water used to irrigate areas accessible to the public, such as residential lawns and edible crops. These systems can minimize the seasonal fluctuations inherent to all reclaimed water systems by allowing storage of reclaimed water during the wet season when demand is low, and recovery of the stored water during dry periods when demand is high. Because the potential storage volume of an ASR system is essentially unlimited, it is expected that these systems will offer a solution to the shortcomings of the traditional storage techniques discussed above.

The use of ASR was also considered as part of the Monterey County, California reuse program in order to overcome seasonal storage issues associated with an irrigation-based project (Jaques and Williams, 1996).

Where water reuse is being implemented to reduce or eliminate wastewater discharges to surface waters, state or local regulations usually require that adequate storage be provided to retain excess wastewater under a specific return period of low demand. In some cold climate states, storage volumes may be specified according to projected non-application days due to freezing temperatures. Failure to retain reclaimed water under the prescribed weather conditions may constitute a violation of an NPDES permit and result in penalties. A method for preparing storage calculations under low demand conditions is provided in the EPA *Process Design Manual: Land Treatment of Municipal Wastewater* (U.S. EPA, 1981 and 1984). In many cases, state regulations will also include a discussion about the methods to be used for calculating the storage that is required to retain water under a given rainfall or low demand return interval. In almost all cases, these methods will be aimed at demonstrating sites with hydrogeologic storage capacity to receive wastewater effluent for the purposes of disposal. In this regard, significant attention is paid to subsurface conditions as they apply to the percolation of effluent into the groundwater with specific concerns as to how the groundwater mound will respond to effluent loading.

The remainder of this section discusses the design considerations for seasonal storage systems. For the purpose of discussion, the projected irrigation demands of turf grass in a hot, humid location (Florida) and a hot, arid location (California) are used to illustrate storage calculations. Irrigation demands were selected for illustration because irrigation is a common use of reclaimed water, and irrigation demands exhibit the largest seasonal fluctuations, which can affect system reliability. However, the general methodologies described in this section can also be applied to other uses of reclaimed water and other locations as long as the appropriate parameters are defined.

3.5.1 Identifying the Operating Parameters

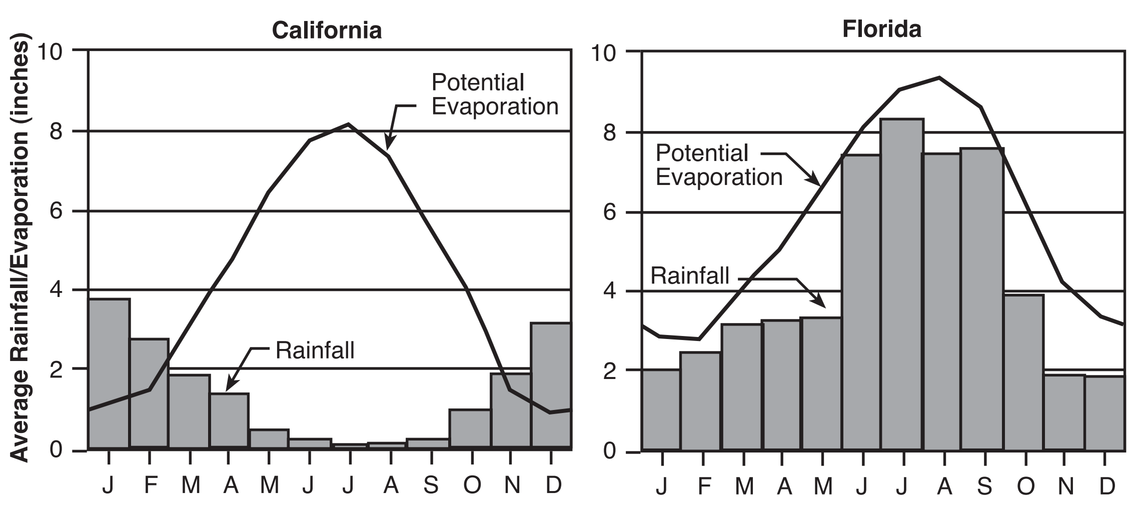
In many cases, a water reuse system will provide reclaimed water to a diverse customer base. Urban reuse customers typically include golf courses and parks and may also include commercial and industrial customers. Such is the case in both the City of St. Petersburg, Florida, and Irvine Ranch Water District, California, reuse programs. These programs provide water for cooling, washdown, and toilet flushing as well as for irrigation. Each water use has a distinctive seasonal demand pattern and, thereby, impacts the need for storage.

Reuse systems have significant differences with traditional land application systems starting with the fundamental objectives of each. Land application systems seek to maximize hydraulic loadings while reuse systems provide nonpotable waters for uses where a higher quality of water is not required. Historical water use patterns should be used where available. Methodologies developed for land application systems are generally poorly suited to define expected demands of an irrigation-based reuse system and should be replaced with methodologies expressly developed to estimate irrigation needs. This point was illustrated well by calculations of storage required to prevent a discharge based on: (1) actual golf course irrigation use over a 5-year period and (2) use of traditional land application water balance methods using site-specific hydrogeological information and temperature and rainfall corresponding to the 5-year record of actual use. Use of historical records estimated a required storage volume of 89 days of flow, while traditional land application methods estimated a required storage volume of 196 days (Ammerman *et al.,* 1997). It should also be noted that, like potable water, the use of reclaimed water is subject to the customer's perceived need for water.

The primary factors controlling the need for supplemental irrigation are evapotranspiration and rainfall. Evapotranspiration is strongly influenced by temperature and will be lowest in the winter months and highest in midsummer. Water use for irrigation will also be strongly affected by the end user and their attention to the need for supplemental water. Where uses other than irrigation are being investigated, other factors will be the driving force for demand. For example, demand for reclaimed water for industrial reuse will depend on the needs of the specific industrial facility. These demands could be estimated based on past water use records, if data are available, or a review of the water use practices of a given industry. When considering the demand for water in a manmade wetland, the system must receive water at the necessary time and rate to ensure that the appropriate hydroperiod is simulated. If multiple uses of reclaimed water are planned from a single source, the factors affecting the demand of each should be identified and integrated into a composite system demand.

Figure 3-12 presents the average monthly potential evaporation and average monthly rainfall in southwest Florida and Davis, California (Pettygrove and Asano,

Figure 3-12. Average Monthly Rainfall and Pan Evaporation



1985). The average annual rainfall is approximately 52 inches (132 cm) per year, with an average annual potential evaporation of 71 inches (180 cm) per year in Florida. The average annual rainfall in Davis is approximately 17 inches (43 cm) per year with a total annual average potential evaporation rate of approximately 52 inches (132 cm) per year.

In both locations, the shape of the potential evaporation curve is similar over the course of the year; however, the distribution of rainfall at the sites differs significantly. In California, rainfall is restricted to the late fall, winter, and early spring, with little rainfall expected in the summer months when evaporation rates are the greatest. The converse is true for the Florida location, where the major portion of the total annual rainfall occurs between June and September.

3.5.2 Storage to Meet Irrigation Demands

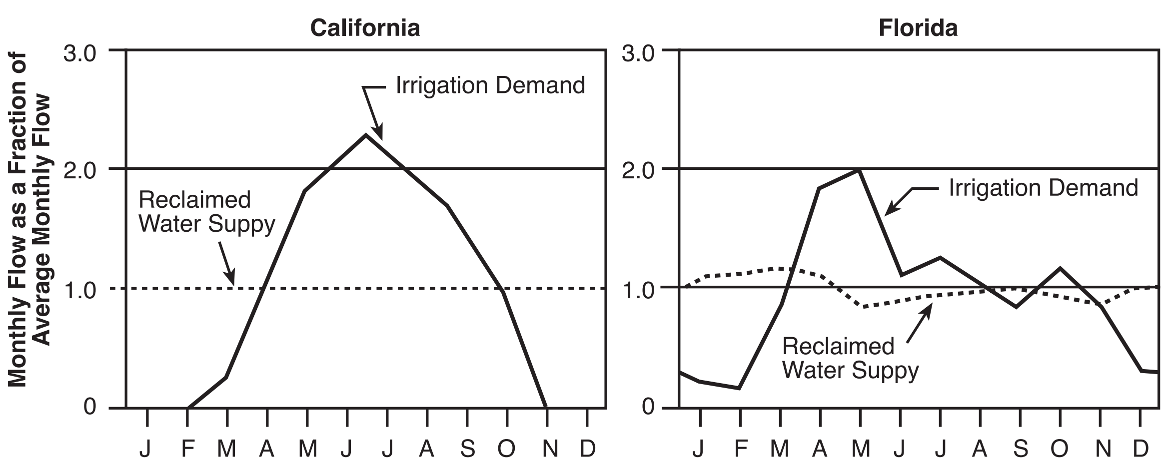
Once seasonal evapotranspiration and rainfall have been identified, reclaimed water irrigation demands throughout the seasons can be estimated. The expected fluctuations in the monthly need for irrigation of grass in Florida and California are presented in **Figure 3-13.** The figure also illustrates the seasonal variation in wastewater flows and the potential supply of irrigation water for both locations. In both locations, the potential monthly supply and demand are expressed as a fraction of the average monthly supply and demand.

To define the expected fluctuations in Florida's reclaimed water supply, historic flow data are averaged for each month. The reclaimed water supply for the Florida example indicates elevated flows in the late winter and early spring with less than average flows in the summer months, reflecting the region's seasonal influx of tourists. The seasonal irrigation demand for reclaimed water in Florida was calculated using the Thornthwaite equation. (Withers and Vipond, 1980). It is interesting to note that even in months where rainfall is almost equal to the potential evapotranspiration, a significant amount of supplemental irrigation may still be required. This occurs as a result of high intensity, short duration, rainfalls in Florida coupled with the relatively poor water-holding capacity of the surficial soils.

The average monthly irrigation demand for California, shown in Figure 3-12, is based on data developed by Pruitt and Snyder (Pettygrove and Asano, 1985). Because significant rainfall is absent throughout most of the growing season, the seasonal pattern of supplemental irrigation for the California site is notably different from that of Florida. For the California example, it has been assumed that there is very little seasonal fluctuation in the potential supply of reclaimed water. If the expected annual average demands of a reclaimed water system are approximately equal to the average annual available supply, storage is required to hold water for peak demand months. Using monthly supply and demand factors, the required storage can be obtained from the cumulative supply and demand. The results of this analysis suggest that, to make beneficial use of all available water under average conditions, the Florida reuse program will require approximately 90 days of storage, while California will need approximately 150 days.

These calculations are based on the estimated consumptive demand of the turf grass. In actual practice, the estimate would be refined, based on site-specific conditions. Such conditions may include the need to leach

Figure 3-13. Average Pasture Irrigation Demand and Potential Supply



salts from the root zone or to intentionally over-apply water as a means of disposal. The vegetative cover receiving irrigation will also impact the condition under which supplemental water will be required. Drought conditions will result in an increased need for irrigation. The requirements of a system to accommodate annual irrigation demands under drought conditions should also be examined.

3.5.3 Operating without Seasonal Storage

Given the challenges of using storage to equalize seasonal supplies and demands, it is not surprising that many utilities choose to commit only a portion of the available reclaimed water flow to beneficial reuse.

A partial commitment of reclaimed water may also have applications in the following situations:

- The cost of providing storage for the entire flow is prohibitive
- Sufficient demand for the total flow is not available
- The cost of developing transmission facilities for the entire flow is prohibitive
- Total abandonment of existing disposal facilities is not cost-effective

Systems designed to use only a portion of the reclaimed water supply are plentiful. It should be noted that a partial commitment of reclaimed water may be able to achieve significant benefits in terms of environmental impacts. Specifically, many surface water discharge permits are based on the 7-day, 10-year (7Q10) low flow expected in the receiving water body. Such events invariably coincide with extended periods of low rainfall, which, in turn, tend to increase the amount of water diverted away from disposal and into the reuse system.

3.6 Supplemental Water Reuse System Facilities

3.6.1 Conveyance and Distribution Facilities

The distribution network includes pipelines, pump stations, and storage facilities. No single factor is likely to influence the cost of water reclamation more than the conveyance or distribution of reclaimed water from its source to its point of use. The design requirements of reclaimed water conveyance systems vary according to the needs of the users. Water quality is, of course, a consideration as well. Reclaimed water systems may present more challenges for both internal and external corrosion than typically experienced in the potable water system. Generally, reclaimed water is more mineralized with a higher conductance and chloride content and lower pH, enhancing the potential for corrosion on the interior of the pipe. Because reclaimed water lines are often the last pipe installed, there is an increased opportunity for stray current electrolysis or coating damage (Ryder, 1996). Design requirements will also be affected by the policies governing the reclamation system (e.g., what level of shortfall, if any, can be tolerated?). Where a dual distribution system is created, the design will be similar to that of a potable system in terms of pressure and volume requirements. However, if the reclaimed water distribution system does not provide for an essential service such as fire protection or sanitary uses, the reliability of the reclamation system need not be as stringent. This, in turn, reduces the need for backup systems, thereby reducing the cost of the system. In addition, an urban reuse program designed primarily for irrigation will experience diurnal and seasonal flows and peak demands that have different design parameters than the fire protection requirements generally used in the design of potable water systems.

The target customer for many reuse programs may be an entity that is not traditionally part of municipal water/wastewater systems. Such is the case with agricultural and large green space areas, such as golf courses, that often rely on wells to provide for nonpotable water uses. Even when these sites are not directly connected to municipal water supplies, reclaimed water service to these customers may be desirable for the following reasons:

- The potential user currently draws water from the same source as that used for potable water, creating an indirect demand on the potable system.
- The potential user has a significant demand for nonpotable water and reuse may provide a cost-effective means to reduce or eliminate reliance on existing effluent disposal methods.
- The potential user is seeking reclaimed water service to enhance the quality or quantity (or both) of the water available.
- A municipal supplier is seeking an exchange of nonpotable reclaimed water for raw water sources currently controlled by the prospective customer.

The conveyance and distribution needs of these sites may vary widely and be unfamiliar to a municipality. For example, a golf course may require flows of 500 gpm (38 l/s) at pressures of 120 psi (830 kPa). However, if the golf course has the ability to store and repump irrigation water, as is often the case, reclaimed water can be delivered at atmospheric pressure to a pond at approximately one-third the instantaneous demand. Where frost-sensitive crops are served, an agricultural customer may wish to provide freeze protection through the irrigation system. Accommodating this may increase peak flows by an order of magnitude. Where customers that have no history of usage on the potable system are to be served with reclaimed water, detailed investigations are warranted to ensure that the service provided would be compatible with the user needs. These investigations should include an interview with the system operator as well as an inspection of the existing facilities.

Figure 3-14 provides a schematic of the multiple reuse conveyance and distribution systems that may be encountered. The actual requirements of a system will be dictated by the final customer base and are discussed in Chapter 2. The remainder of this section discusses issues pertinent to all reclaimed water conveyance and distribution systems.

A concentration or cluster of users results in lower customer costs for both capital and O&M expenses than a delivery system to dispersed users. Initially, a primary skeletal system is generally designed to serve large institutional users who are clustered and closest to the treatment plant. A second phase may then expand the system to more scattered and smaller users, which receive nonpotable water from the central arteries of the nonpotable system. Such an approach was successfully implemented in the City of St. Petersburg, Florida. The initial customers were institutional (e.g., schools, golf courses, urban green space, and commercial). However, the lines were sized to make allowance for future service to residential customers.

As illustrated in St. Petersburg and elsewhere, once reclaimed water is made available to large users, a secondary customer base of smaller users often request service. To ensure that expansion can occur to the projected future markets, the initial system design should model sizing of pipes to satisfy future customers within any given zone within the service area. At points in the system, where a future network of connections is anticipated, such as a neighborhood, turnouts should be installed. Pump stations and other major facilities involved in conveyance should be designed to allow for planned expansion. Space should be provided for additional pumps, or the capacities of the pumps may be expanded by changes to impellers and/or motor size. Increasing a pipe diameter by one size is economically justified since over half the initial cost of installing a pipeline is for excavation, backfill, and pavement.

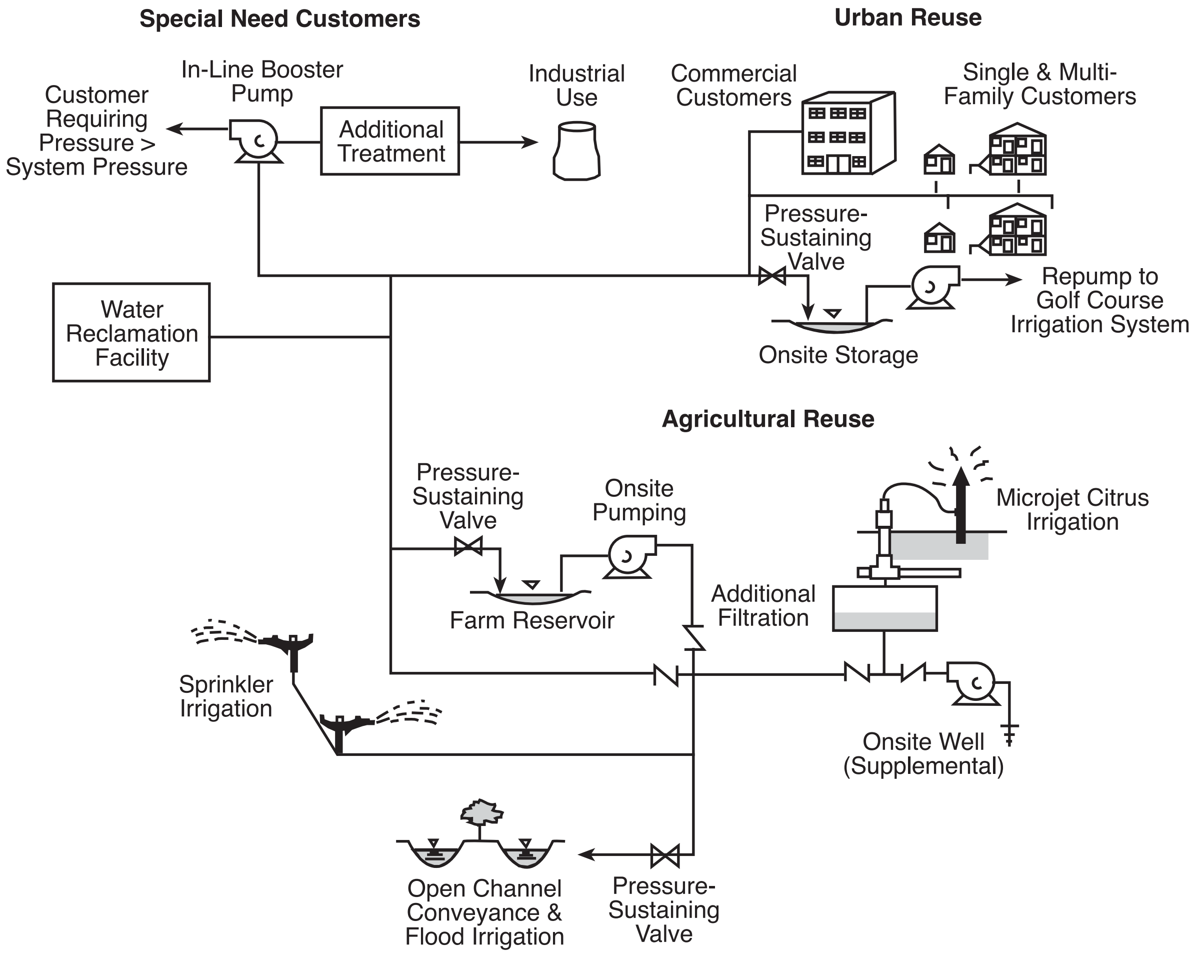
A potable water supply system is designed to provide round-the-clock, "on-demand" service. Some nonpotable systems allow for unrestricted use, while others place limits on the hours when service is available. A decision on how the system will be operated will significantly affect system design. Restricted hours for irrigation (i.e., only evening hours) may shift peak demand and require greater pumping capacity than if the water was used over an entire day or may necessitate a programmed irrigation cycle to reduce peak demand. The Irvine Ranch Water District, California, though it is an "on-demand" system, restricts landscape irrigation to the hours of 9 p.m. to 6 a.m. to limit public exposure. Due to the automatic timing used in most applications, the peak hour demand was found to be 6 times the average daily demand and triple that of the domestic water distribution system (Young *et al*., 1987). The San Antonio Water System (Texas) established a requirement for onsite storage for all users with a demand greater than 100 acre-feet per year as a means of managing peak demands. As noted previously, attributes such as freeze protection may result in similar increases in peak demands of agricultural systems.

System pressure should be adequate to meet the user's needs within the reliability limits specified in a user agreement or by local ordinance. The Irvine Ranch Water District, California runs its system at a minimum of 90 psi (600 kPa). The City of St. Petersburg, Florida currently operates its system at a minimum pressure of 60 psi (400 kPa). However, the City of St. Petersburg is recommending that users install low-pressure irrigation devices, which operate at 50 psi (340 kPa) as a way of transferring to a lower pressure system in the future to reduce operating costs. The City of Orlando, Florida is designing a regional urban reuse system with a target minimum pressure in the transmission main of 50 psi (350 KPa) at peak hour conditions (CDM, 2001).

When significant differences in elevations exist within the service area, the system should be divided into pressure zones. Within each zone, a maximum and minimum delivery pressure is established. Minimum delivery pressures may be as low as 10 psi (70 kPa) and maximum delivery pressures may be as high as 150 psi (1,000 kPa), depending on the primary uses of the water.

Several existing guidelines recommend operating the nonpotable system at pressures lower than the potable system (i.e., 10 psi, 70 kPa lower) in order to mitigate any cross-connections. However, experience in the field indicates that this is difficult to achieve at all times throughout the distribution system.

Figure 3-14. Example of a Multiple Reuse Distribution System



3.6.1.1 Public Health Safeguards

The major concern guiding design, construction, and operation of a reclaimed water distribution system is the prevention of cross-connections. A cross-connection is a physical connection between a potable water system used to supply water for drinking purposes, and any source containing nonpotable water through which potable water could be contaminated.

Another major concern is to prevent improper use or inadvertent use of reclaimed water as potable water. To protect public health from the outset, a reclaimed water distribution system should be accompanied by health codes, procedures for approval (and disconnection) of service, regulations governing design and construction specifications, inspections, and operation and maintenance staffing. Public health protection measures that should be addressed in the planning phase are identified below.

- Establish that public health is the overriding concern
- Devise procedures and regulations to prevent cross-connections
- Develop a uniform system to mark all nonpotable components of the system
- Prevent improper or unintended use of nonpotable water through a proactive public information program
- Provide for routine monitoring and surveillance of the nonpotable system
- Establish and train special staff members to be responsible for operations, maintenance, inspection, and approval of reuse connections
- Develop construction and design standards

- Provide for the physical separation of the potable water, reclaimed water, sewer lines and appurtenances

Successful methods for implementing these measures are outlined below.

a. Identification of Pipes and Appurtenances

All components and appurtenances of the nonpotable system should be clearly and consistently identified throughout the system. Identification should be through color coding and marking. The nonpotable system (i.e., pipes, pumps, outlets, and valve boxes) should be distinctly set apart from the potable system. The methods most commonly used are unique colorings, labeling, and markings.

Nonpotable piping and appurtenances are painted purple or can be integrally stamped or marked, "CAUTION NONPOTABLE WATER – DO NOT DRINK" or "CAUTION: RECLAIMED WATER – DO NOT DRINK," or the pipe may be wrapped in purple polyethylene vinyl wrap. Another identification method is to mark pipe with colored marking tape or adhesive vinyl tape. When tape is used, the words ("CAUTION: RECLAIMED WATER – DO NOT DRINK") should be equal to the diameter of the pipe and placed longitudinally at 3-feet (0.9-meters) intervals. Other methods of identification and warning are: stenciled pipe with 2- to 3-inch (5- to 8-cm) letters on opposite sides, placed every 3 to 4 feet (0.9 to 1.2 meters); for pipe less than 2 inches (5 cm), lettering should be at least 5/8-inch (1.6 cm) at 1-foot (30-cm) intervals; plastic marking tape (with or without metallic tracer) with lettering equal to the diameter of pipe, continuous over the length of pipe at no more than 5-foot (1.5-meter) intervals; vinyl adhesive tape may be placed at the top of the pipe for diameters 2.5 to 3 inches (6 to 8 cm) and along opposite sides of the pipe for diameters 6 to 16 inches (15 to 40 cm), and along both sides and on top of the pipe for diameters of 20 inches (51 cm) or greater (AWWA, 1994).

The FDEP requires all new advisory signs and labels on vaults, service boxes, or compartments that house hose bibs, along with all labels on hose bibs, valves, and outlets, to bear the words, "do not drink" and "no beber," along with the equivalent standard international symbol. In addition to the words, "do not drink" and "no beber," advisory signs posted at storage ponds and decorative water features also bear the words, "do not swim" and "no nadar," along with the equivalent standard international symbols. **Figure 3-15** shows a typical reclaimed water advisory sign. Existing advisory signs and labels will be retrofitted, modified, or replaced in order to comply with the revised wording requirements as part of the permit renewal process for FDEP (FDEP, 1999).

Figure 3-15. Reclaimed Water Advisory Sign

Valve boxes for hydraulic and electrical components should be colored and warnings should be stamped on the cover. The valve covers for nonpotable transmission lines should not be interchangeable with potable water covers. For example, the City of Altamonte Springs, Florida uses square valve covers for reclaimed water and round valve covers for potable water. Blow-off valves should be painted and carry markings similar to other system piping. Irrigation and other control devices should be marked both inside and outside. Any constraints or special instructions should be clearly noted and placed in a suitable cabinet. If fire hydrants are part of the system, they should be painted or marked and the stem should require a special wrench for opening.

b. Horizontal and Vertical Separation of Potable from Nonpotable Pipes

The general rule is that a 10-foot (3-meter) horizontal interval and a 1-foot (0.3-meter) vertical distance should be maintained between potable (or sewer) lines and nonpotable lines that are parallel to each other. When these distances cannot be maintained, special authorization may be required, though a minimum lateral distance of 4 feet (1.2 meters) (St. Petersburg) is generally mandatory. The State of Florida specifies a 5-foot (1.5-meter) separation between reclaimed water lines and water lines or force mains, with a minimum of 3-foot (0.9-meter) separation from pipe wall to pipe wall (FDEP, 1999). This arrangement allows for the installation of reclaimed water lines between water and force mains that are separated by 10 feet (3 meters). The potable water should be placed above the nonpotable, if possible. Under some circumstances, using a reclaimed water main of a different depth than that of potable or force mains might be considered to provide further protection from having an inadvertent cross–connection occur. Nonpotable lines are usually required to be at least 3 feet (90 cm) below ground. **Figure 3-16** illustrates Florida's separation requirements for nonpotable lines.

c. Prevent Onsite Ability to Tie into Reclaimed Water Lines

The Irvine Ranch Water District, California has regulations mandating the use of special quick coupling valves for onsite irrigation connections. For reclaimed water, these valves are operated by a key with an Acme thread. This thread is not allowed for the potable system. The cover on the reclaimed water coupler is different in color and material from that used on the potable system. Hose bibs are generally not permitted on nonpotable systems because of the potential for incidental use and possible human contact with the reclaimed water. Below-ground bibs placed inside a locking box or that require a special tool to operate are allowed by Florida regulations (FDEP, 1999).

d. Backflow Prevention

Where the possibility of cross-connection between potable and reclaimed water lines exists, backflow prevention devices should be installed onsite when both potable and reclaimed water services are provided to a user. The backflow prevention device is placed on the potable water service line to prevent potential backflow from the reclaimed water system into the potable water system if the 2 systems are illegally interconnected. Accepted methods of backflow prevention include:

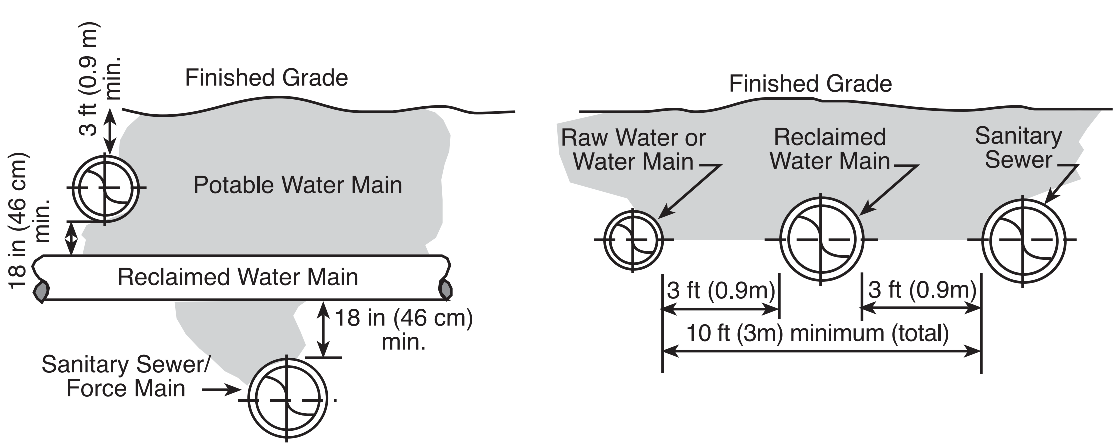
- Air gap
- Reduced-pressure principal backflow prevention assembly
- Double-check valve assembly
- Pressure vacuum breaker
- Atmospheric vacuum breaker

The AWWA recommends the use of a reduced-pressure principal backflow prevention assembly where reclaimed water systems are present. However, many communities have successfully used double-check valve assemblies. The backflow prevention device will prevent water expansion into the water distribution system. At some residences, the tightly closed residential water system can create a pressure buildup that causes the safety relief on a water heater to periodically discharge. This problem was solved by the City of St. Petersburg, Florida, by providing separate pressure release valves, which allow for the release of water through an outdoor hose bibb.

If potable water is used as make-up water for lakes or reservoirs, there should be a physical break between the potable water supply pipe and receiving reservoir. The air gap separating the potable water from the reservoir containing nonpotable water should be at least 2 pipe diameters. There should never be any permanent connection between nonpotable and potable lines in the system.

In most cases, backflow prevention devices are not provided on a reclaimed water system. However, the San Antonio Water System (Texas) requires a reduced-pres-

Figure 3-16. Florida Separation Requirements for Reclaimed Water Mains



sure principal backflow preventer on the potable supply to properties using reclaimed water. In addition, the City requires customers to use a double-check assembly or air gap on the reclaimed water supply. This provision is basic to maintaining a consistent water quality in the San Antonio reclaimed water supply. It is prudent to periodically inspect the potable system to confirm that cross-connections do not exist. The City of San Antonio alternately shuts down the potable and reclaimed water at a site. The inactive system is then checked for residual pressure, indicating a cross- connection. Where possible, dye tests are also conducted (Baird, 2000). The City of Altamonte Springs, Florida takes its entire reuse system off line for 2 days each year as part of its cross-connection control program.

e. Safeguards when Converting Existing Potable Lines to Nonpotable Use

In cases where parts of the system are being upgraded and some of the abandoned potable water lines are being transferred to the nonpotable system, care must be taken to prevent any cross-connections from occurring. As each section is completed, the new system should be shutdown and drained and each water user checked to ensure that there are no improper connections. Additionally, a tracer, such as potassium permanganate, may be introduced into the nonpotable system to test whether any of it shows up at any potable fixture.

In existing developments where an in-place irrigation system is being converted to carry reclaimed water, the new installation must be inspected and tested with tracers or some other method to ensure separation of the potable from the nonpotable supply. It may warrant providing a new potable service line to isolated potable facilities. For example, if a park is converting to reclaimed water, rather than performing an exhaustive evaluation to determine how a water fountain was connected to the existing irrigation system, it could be simpler to supply a new service lateral from the new water main.

3.6.1.2 Operations and Maintenance

Maintenance requirements for the nonpotable components of the reclaimed water distribution system should be the same as those for potable. As the system matures, any disruption of service due to operational failures will upset the users. From the outset, such items as isolation valves, which allow for repair to parts of the system without affecting a large area, should be designed into the nonpotable system. Flushing the line after construction should be mandatory to prevent sediment from accumulating, hardening, and becoming a serious future maintenance problem.

Differences in maintenance procedures for potable and nonpotable systems cannot generally be forecast prior to the operation of each system. For instance, the City of St. Petersburg, Florida flushes its nonpotable lines twice a year during the off-season months. The amount of water used in the flushing is equal to a day's demand of reclaimed water. The Irvine Ranch Water District (California) reports no significant difference in the 2 lines, though the reclaimed lines are flushed more frequently (every 2 to 3 years versus every 5 to 10 years for potable) due to suspended matter and sediment picked up during lake storage. Verification that adequate disinfection has occurred as part of treatment prior to distribution to reclaimed water customers is always required. However, maintenance of a residual in the transmission/distribution system is not required. Florida requires a 1-mg/l chlorine residual at the discharge of the chlorine contact basin, but no minimum residual is required in the reclaimed water piping system. The State of Washington is an exception in that it does require a minimum of 0.5-mg/l-chlorine residual in the distribution lines.

a. Blow-Offs/Flushing Hydrants

Even with sufficient chlorination, residual organics and bacteria may grow at dead spots in the system, which may lead to odor and clogging problems. Flushing and periodic maintenance of the system can significantly allay the problem. In most cases, the flushing flow is directed into the sewage system.

b. Flow Recording

Even when a system is unmetered, accurate flow recording is essential to manage the growth of the system. Flow data are needed to confirm total system use and spatial distribution of water supplied. Such data allow for efficient management of the reclaimed water pump stations and formulations of policies to guide system growth. Meters placed at the treatment facility may record total flow and flow-monitoring devices may be placed along the system, particularly in high consumption areas.

c. Permitting and Inspection

The permitting process includes plan and field reviews followed by periodic inspections of facilities. This oversight includes inspection of both onsite and offsite facilities. Onsite facilities are the user's nonpotable water facilities downstream from the reclaimed water meter. Offsite facilities are the agency's nonpotable water facilities up to and including the reclaimed water meter.

Though inspection and review regulations vary from system to system, the basic procedures are essentially the same. These steps are described below.

(1) Plan Review – A contractor (or resident) must request service and sign an agreement with the agency or department responsible for permitting reclaimed water service. Dimensioned plans and specifications for onsite facilities must conform to regulations. Usually, the only differences from normal irrigation equipment will be identification requirements and special appurtenances to prevent cross-connections. Some systems, however, require that special strainer screens be placed before the pressure regulator for protection against slime growths fouling the sprinkler system, meter, or pressure regulator.

The plans are reviewed and the agency works with the contractor to make sure that the system meets all requirements. Systems with cross-connections to potable water systems must be denied. Temporary systems should not be considered. Devices for any purpose other than irrigation should be approved through special procedures.

Installation procedures called out on the plan notes are also reviewed because they provide the binding direction to the landscape contractor. All points of connection are reviewed for safety and compatibility. The approved record drawings ("as-builts") are kept on file. The "as-builts" include all onsite and offsite nonpotable water facilities as constructed or modified, and all potable water and sewer lines.

(2) Field Review – Field review is generally conducted by the same staff involved in the plan review. Staff looks for improper connections, unclear markings, and insufficient depths of pipe installation. A cross-connection control test is performed, followed by operation of the actual onsite irrigation system to ensure that overspraying and overwatering are not occurring. Any problems identified are then corrected. Follow-up inspections are routine, and in some cases, fixed interval (e.g. semi-annual) inspections and random inspections are planned.

(3) Monitoring – A number of items should be carefully monitored or verified, including:

- Requiring that landscape contractors or irrigation contractors provide at least minimal education to their personnel so that these contractors are familiar with the regulations governing reclaimed water installations
- Submitting all modifications to approved facilities to the responsible agencies
- Detecting and recording any breaks in the transmission main
- Randomly inspecting user sites to detect any faulty equipment or unauthorized use
- Installing monitoring stations throughout the system to test pressure, chlorine residual, and other water quality parameters

A reclaimed water supplier should reserve the right to withdraw service for any offending condition subject to correction of the problem. Such rights are often established as part of a user agreement or a reuse ordinance. Chapter 5 provides a discussion of the legal issues associated with reclaimed water projects.

3.6.2 Operational Storage

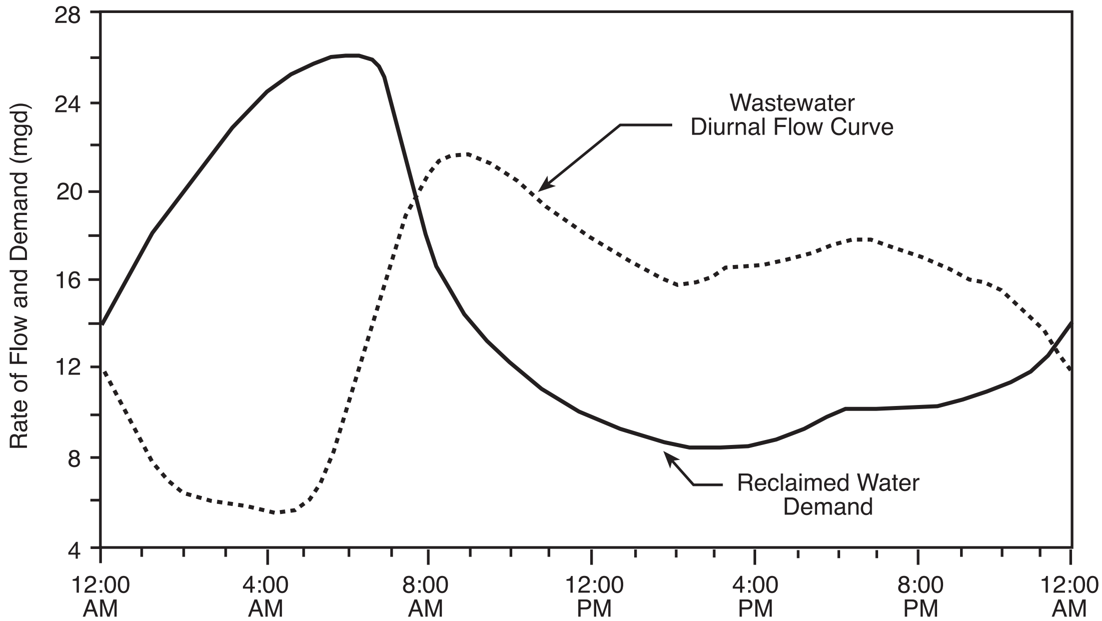
As with potable water distribution systems, a reclaimed water system must provide sufficient operational storage to accommodate diurnal fluctuations in demand and supply. The volume required to accommodate this task will depend on the interaction of the supply and demand over a 24-hour period.

Designs are dependent on assessments of the diurnal demand for reclaimed water. Such assessments, in most cases, require a detailed investigation of the proposed user or users. When possible, records of actual historical use should be examined as a means to develop demand requirements. Where records are absent, site-specific investigations are in order. In some cases, pilot studies may be warranted prior to initiating a full-scale reuse program.

Figure 3-17 presents the anticipated diurnal fluctuation of supply and urban irrigation demand for a proposed reclaimed water system in Boca Raton, Florida (CDM, 1991). This information was developed based on the historic fluctuations in wastewater flow experienced in Boca Raton and the approximate fluctuations in the reclaimed water urban irrigation demand experienced in the St. Petersburg, Florida urban reuse program.

Operational storage may be provided at the reclamation facility, as remote storage out in the system, or as a combination of both. For example, the City of Altamonte

Figure 3-17. Anticipated Daily Reclaimed Water Demand Curve vs. Diurnal Reclaimed Water Flow Curve



Springs, Florida, maintains ground storage facilities at the reclamation plant and elevated storage tanks out in the reclaimed water system. Large sites, such as golf courses, commonly have onsite ponds capable of receiving water throughout the day. Such onsite facilities reduce operational storage requirements that need to be provided by the utility. In the City of Naples, Florida where reclaimed water is provided to 9 golf courses, remote booster pump stations deliver reclaimed water to users from a covered storage tank located at the reclamation plant.

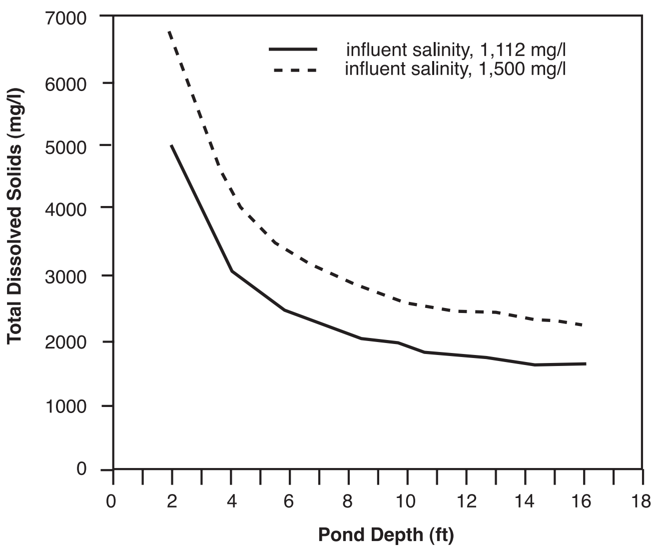
Operational storage facilities are generally covered tanks or open ponds. Covered storage in ground or elevated tanks is used for unrestricted urban reuse where aesthetic considerations are important. Ponds are less costly, in most cases, but generally require more land per gallon stored. Where property costs are high or sufficient property is not available, ponds may not be feasible. Open ponds also result in water quality degradation from biological growth, and chlorine residual is difficult to maintain. Ponds are appropriate for onsite applications such as agricultural and golf course irrigation. In general, ponds that are already being used as a source for irrigation are also appropriate for reclaimed water storage. In addition to the biological aspects of storing reclaimed water in onsite impoundments, the concentration of various constituents due to surface evaporation may present a problem. Reclaimed water often has a more elevated concentration of TDS than other available sources of water. Where evaporation rates are high and rainfall is low, the configuration of onsite storage ponds was found to have significant impacts on water quality in terms of TDS (Chapman and French, 1991). Shallow ponds with a high area-to-volume ratio experience greater concentrations of dissolved solids due to surface evaporation. Dissolved solids increase in all ponds, but deeper ponds can mitigate the problem. **Figure 3-18** summarizes the expected concentration levels of TDS with varying pond depth for reclaimed water with an influent concentration of 1,112 and 1,500 mg/l of TDS, assuming water is lost from storage through evaporation only.

3.6.3 Alternative Disposal Facilities

Beneficial water reclamation and reuse can effectively augment existing water supplies and reduce the water quality impacts of effluent discharge. Yet 100 percent reuse of the effluent may not always be feasible. In such cases, some form of alternative use or disposal of the excess water is necessary. For the purposes of this section, the discharge of reclaimed water will be considered “disposal,” regardless of whether it is for subsequent reuse or permanent disposal.

Where reclamation programs incorporate existing wastewater treatment facilities, an existing disposal system will likely be in place and can continue to be used for partial or intermittent disposal. Common alternative disposal systems include surface water discharge, injection wells, land application, and wetlands application.

Figure 3-18. TDS Increase Due to Evaporation for One Year as a Function of Pond Depth



These methods are described below.

3.6.3.1 Surface Water Discharge

Intermittent surface water discharge may provide an acceptable method for the periodic disposal of excess reclaimed water. While demand for reclaimed water normally declines during wet weather periods, it is during wet weather periods that surface waters are generally more able to assimilate the nutrients in reclaimed water without adverse water quality impacts. Conversely, during the warm summer months when surface water bodies are often most susceptible to the water quality impacts of effluent discharges, the demand for irrigation water is high and an excess of reclaimed water is less likely. Thus, the development of a water reuse program with intermittent discharges can reduce or eliminate wastewater discharges during periods when waters are most sensitive to nutrient concentrations while allowing for discharges at times when adverse impacts are less likely. By eliminating discharges for a portion of the year through water reuse, a municipality may also be able to avoid the need for costly advanced wastewater treatment nutrient removal processes often required for a continuous discharge. The New York City's investigation into water reclamation included a comparison of the reduction in nitrogen loadings that could be achieved through BNR treatment or beneficial reuse. **Table 3-15** provides a summary of this effort and indicates the volume of water that must be diverted to reuse in order to equal the nutrient reduction that would be realized from a given level of BNR treatment.

In the City of Petaluma, California the ability to protect the downstream habitat by eliminating surface water discharges from May through September played a major role in considering reuse. (Putnam, 2002).

3.6.3.2 Injection Wells

Injection wells, which convey reclaimed water into subsurface formations, are also used as an alternative means of disposal, including eventual reuse via groundwater recharge. Thus, the purpose of the disposal (permanent or for future reuse) will typically determine the type and regulatory framework of the injection wells. The EPA Underground Injection Control (UIC) program has categorized injection wells into 5 classes, only 2 of which (Class I and V) apply to reclaimed water disposal.

Class I injection wells are technologically sophisticated and inject hazardous and non-hazardous wastes below the lowermost underground source of drinking water (USDW). Injection occurs into deep, isolated rock formations that are separated from the lowermost USDW by layers of impermeable clay and rock. In general, owners and operators of most new Class I injection wells are required to:

- Site the injection wells in a location that is free of faults and other adverse geological features. Drill to a depth that allows the injection into formations that do not contain water that can potentially be used as a source of drinking water. These injection zones are confined from any formation that may contain water that may potentially be used as a source of drinking water.
- Inject through an internal pipe (tubing) that is located inside another pipe (casing). This outer pipe has cement on the outside to fill any voids occurring between the outside pipe and the hole that was bored for the well (borehole). This allows for multiple layers of containment of the potentially contaminating injection fluids.
- Test for integrity at the time of completion and every 5 years thereafter (more frequently for hazardous waste wells).
- Monitor continuously to assure the integrity of the well.

Class V injection wells will likely include nearly all reclaimed water injection wells that are not permitted as Class I injection wells. Under the existing federal regulations, Class V injection wells are "authorized by rule" (40 CFR 144), which means they do not require a federal permit if they do not endanger underground sources of drinking water and comply with other UIC program requirements. However, individual states may require specific treatment, well construction, and water quality monitoring standards compliance before permitting any injection of reclaimed water into aquifers that are currently or could potentially be used for potable supply. A discussion about potential reclaimed water indirect potable reuse guidelines is contained in Chapter 4.

Injection wells are a key component of the urban reuse program in the City of St. Petersburg, Florida. The city operates 10 wells, which inject excess reclaimed water into a saltwater aquifer at depths between 700 and 1,000 feet (210 and 300 meters) below the land surface. Approximately 50 percent of the available reclaimed water is disposed of through injection. When originally installed, the wells were permitted as Class I injection wells with the primary use for the management of excess reclaimed water, but also were employed to dispose of any reclaimed water not meeting water quality standards. The City is in the permitting process to convert the wells to Class V injection wells, for primary use as an ASR system.

Under suitable circumstances, excess reclaimed water can be stored in aquifers for subsequent reuse. In Orange County, California injection of reclaimed water into potable supply aquifers has been conducted for seawater intrusion control and groundwater recharge since 1976 and has expanded in recent years to Los Angeles County, California. New advanced water treatment and injection projects are underway in both counties to supply the majority of coastal injection wells in Orange and Los Angeles counties with reclaimed water to reduce dependence on imported water from the Colorado River and northern California. Additional discussion about reclaimed water recharge can be found in Chapter 2.

3.6.3.3 Land Application

In water reuse irrigation systems, reclaimed water is applied in quantities to meet an existing water demand. In land treatment systems, effluent may be applied in excess of the needs of the crop. Land application systems can provide reuse benefits, such as irrigation and/or groundwater recharge. However, in many cases, the main focus of land application systems is to avoid detrimental impacts to groundwater that can result from the application of nutrients or toxic compounds.

In some cases, a site may be amenable to both reuse and “land application”. Such are the conditions of a Tallahassee, Florida sprayfield system. This system is located on a sand ridge, where only drought-tolerant flora can survive without irrigation. By providing reclaimed water for irrigation, the site became suitable for agricultural production of multiple crop types. However, because of the extreme infiltration and percolation rates, it is possible to apply up to 3 inches per week (8 cm per week) of reclaimed water without significant detrimental impacts to the crop (Allhands and Overman, 1989).

The use of land application as an alternative means of disposal is subject to hydrogeological considerations. The EPA manual *Land Treatment of Municipal Wastewater* (U.S. EPA, 1981) provides a complete discussion of the design requirements for such systems.

The use of land application systems for wet weather disposal is limited unless high infiltration and percolation rates can be achieved. This can be accomplished through the use of rapid infiltration basins or manmade wetlands.

In cases where manmade wetlands are created, damaged wetlands are restored, or existing wetlands are en-

Table 3-15. Nitrogen Mass Removal Strategies: Nutrient Removal vs. Water Reuse

Water Pollution Control Facility	1998 Total Flow (mgd)	1998 Effluent TN (lbs/d)	Step Feed BNR Projected TN Discharge (lbs/d)	Equivalent Water Reuse (mgd)	Enhanced Step Feed BNR & Separate Centrate Treatment (lbs/d)	Equivalent Water Reuse (mgd)
Wards Island	224	29,000	24,000	39	12,500	128
Hunts Point	134	19,000	16,000	22	9,500	67
Tallman Island	59	7,700	3,500	33	3,500	33
Bowery Bay	126	19,700	11,000	56	6,500	85
26th Ward	69	15,500	7,500	36	5,000	48

hanced, wetlands application may be considered a form of water reuse, as discussed in Section 2.5.1. Partial or intermittent discharges to wetlands systems have also been incorporated as alternative disposal means in water reuse systems, with the wetlands providing additional treatment through filtration and nutrient uptake.

A wetlands discharge is used in Orange County, Florida, where a portion of the reclaimed water generated by the Eastern Service Area WWTF is reused for power plant cooling, and the remainder is discharged by overland flow to a system of manmade and natural wetlands. **Figure 3-19** shows the redistribution construction wetlands system. Application rates are managed to simulate natural hydroperiods of the wetland systems (Schanze and Voss, 1989).

3.7 Environmental Impacts

Elimination or reduction of a surface water discharge by reclamation and reuse generally reduces adverse water

Figure 3-19. Orange County, Florida, Redistribution Constructed Wetland

quality impacts to the receiving water. However, moving the discharge from a disposal site to a reuse system may have secondary environmental impacts. An environmental assessment may be required to meet state or local regulations and is required whenever federal funds are used. Development of water reuse systems may have unintended environmental impacts related to land use, stream flow, and groundwater quality. Formal guidelines for the development of an environmental impact statement (EIS) have been established by the EPA. Such studies are generally associated with projects receiving federal funding or new NPDES permits and are not specifically associated with reuse programs. Where an investigation of environmental impacts is required, it may be subject to state policies.

The following conditions are given as those that would induce an EIS in a federally-funded project:

- The project may significantly alter land use.
- The project is in conflict with any land use plans or policies.
- Wetlands will be adversely impacted.
- Endangered species or their habitat will be affected.
- The project is expected to displace populations or alter existing residential areas.
- The project may adversely affect a flood plain or important farmlands.
- The project may adversely affect parklands, preserves, or other public lands designated to be of scenic, recreational, archaeological, or historical value.
- The project may have a significant adverse impact upon ambient air quality, noise levels, surface or groundwater quality or quantity.
- The project may have adverse impacts on water supply, fish, shellfish, wildlife, and their actual habitats.

The types of activities associated with federal EIS requirements are outlined below. Many of the same requirements are incorporated into environmental assessments required under state laws.

3.7.1 Land Use Impacts

Water reuse can induce significant land use changes, either directly or indirectly. Direct changes include shifts in vegetation or ecosystem characteristics induced by alterations in water balance in an area. Indirect changes include land use alterations associated with industrial, residential, or other development made possible by the added supply of water from reuse. Two cases from Florida illustrate this point.

- A study in the Palm Beach County, Florida area determined that reuse could provide water supply sufficient to directly and substantially change the hydroperiod in the area. This change was significant enough to materially improve the potential for sustaining a wetlands ecosystem and for controlling the extent and spread of invasive species. In short, the added reuse water directly affected the nature of land cover in the area.

- Indirect changes were also experienced in agricultural land use in the Orange County, Florida area. Agricultural use patterns were found to be materially influenced by water reuse associated with the Water Conserv II project. Commercial orange groves were sustained and aided in recovery from frost damage to crops by the plentiful supply of affordable water generated by reuse. The added reuse water affected the viability of agriculture, and therefore, indirectly affected land use in the area.

Other examples of changes in land use as a result of available reuse water include the potential for urban or industrial development in areas where natural water availability limits the potential for growth. For example, if the supply of potable water can be increased through recharge using reuse supply, then restrictions to development might be reduced or eliminated. Even nonpotable supplies, made available for uses such as residential irrigation, can affect the character and desirability of developed land in an area. Similar effects can also happen on a larger scale, as municipalities in areas where development options are constrained by water supply might find that nonpotable reuse enables the development of parks or other amenities that were previously considered to be too costly or difficult to implement. Commercial users such as golf courses, garden parks, or plant nurseries have similar potential for development given the presence of reuse supplies.

The potential interactions associated with land use changes are complex, and in some cases the conclusion that impacts are beneficial is subjective. An increase in urban land use, for example, is not universally viewed as a positive change. For this reason, the decision-making process involved in implementing a reclamation program should result from a careful consideration of stakeholder goals.

3.7.2 Stream Flow Impacts

Instream flows can either increase or decrease as a consequence of reuse projects. In each situation where reuse is considered, there is the potential to shift water balances and effectively alter the prevailing hydrologic regime in an area. Two examples of the way flows can increase as a result of a reuse project are as follows:

- In streams where dry weather base flows are groundwater dependant, land application of reclaimed water for irrigation or other purposes can cause an increase in base flows, if the prevailing groundwater elevation is raised. (Groundwater effects are discussed further in Section 3.7.3.)

- Increases in stream flows during wet periods can result from reduced soil moisture capacity in a tributary watershed, if there is pervasive use of recharge on the land surface during dry periods. In such a case, antecedent conditions are wetter, and runoff greater, for a given rainstorm. The instream system bears the consequences of this change.

It is important to note that the concurrent effects of land use changes discussed in Section 3.7.1 can exacerbate either of the above effects.

Instream flow reduction is also possible, and can be more directly evident. For example, the Trinity River in Texas, in the reaches near the City of Dallas, maintains a continuous flow of several hundred cubic feet per second during dry periods. This flow is almost entirely composed of treated effluent from discharges further upstream. If extensive reuse programs were to be implemented at the upstream facilities, dry weather flows in this river would be jeopardized and plans for urban development downstream could be severely impacted due to lack of available water.

In addition to water quantity issues, reuse programs can potentially impact aesthetics or recreational use and damage ecosystems associated with streams where hydrologic behavior is significantly affected. Where wastewater discharges have occurred over an extended period of time, the flora and fauna can adapt and even become dependent on that water. A new or altered ecosystem can arise, and a reuse program implemented without consideration of this fact could have an adverse impact on such a community. In some cases, water reuse projects have been directly affected by concerns for instream flow reduction that could result from a reuse program. The San Antonio Water System (SAWS) in Texas defined the historic spring flow at the San Antonio River headwaters during development of their reclaimed water system. In cooperation with downstream users and the San Antonio River Authority, SAWS agreed to maintain a release of 55,000 acre-feet per year (68×10^6 m^3 per year) from its water reclamation facilities. This policy protects and enhances downstream water quality and provides 35,000 acre-feet per year (43×10^6 m^3 per year) of reclaimed water for local use.

In the State of Washington, reuse water can be discharged to a stream as stream flow augmentation. Under this provision, reclaimed water can be discharged to surface water for purposeful uses such as:

- If the flow is to maintain adequate flows for aquatic life
- If the reclaimed water is going to be used downstream and therefore the stream is acting as a conduit

In the City of Sequim, Washington 0.1 cfs (2.8 l/s) of reclaimed water is discharged into the Bell Stream to keep the benthic layer wet. The flow is not intended to maintain an environment for fish, but instead to maintain other small species that live in the streambed. To date, no studies have been conducted to show the effects to the ecosystem.

The implication of these considerations is that a careful analysis of the entire hydrologic system is an appropriate consideration in a reuse project if instream impacts are to be understood. This is particularly the case when the magnitude of the flows impacted by the reuse program is large, relative to the quantities involved in the hydrologic system that will be directly impacted by the reuse program.

3.7.3 Hydrogeological Impacts

As a final environmental consideration of water reuse, the groundwater quality effects of the reclaimed water for the intended use must be reviewed. The exact concerns of any project are evaluated on a case-by-case basis. One of the better-known sources of potential groundwater pollution is nitrate, which may be found in, or result from, the application of reclaimed water. However, additional physical, chemical, and biological constituents found in reclaimed water may pose an environmental risk. In general, these concerns increase when there are significant industrial wastewater discharges to the water reclamation facility.

Impacts of these constituents are influenced by the hydrogeology of the reuse application site. Where karst conditions exist, for example, constituents may potentially exist within the reclaimed water that will ultimately reach the aquifer. In many reclaimed water irrigation programs, a groundwater-monitoring program is required to detect the impacts of reclaimed water constituents.

3.8 Case Studies

3.8.1 Code of Good Practices for Water Reuse

The Florida Department of Environmental Protection (FDEP) and the Florida Water Environment Association's (FWEA) Water Reuse committee have developed the Code of Good Practices for Water Reuse in Florida (FDEP, 2002). The Code of Good Practices includes 16 principles and is designed to aid reuse utilities as they implement quality water reuse programs.

Protection of Public Health and Environmental Quality

Public Health Significance – To recognize that distribution of reclaimed water for nonpotable purposes offers potential for public contact and that such contact has significance related to the public health.

Compliance – To comply with all applicable state, federal, and local requirements for water reclamation, storage, transmission, distribution, and reuse of reclaimed water.

Product – To provide reclaimed water that meets state treatment and disinfection requirements and that is safe and acceptable for the intended uses when delivered to the end users.

Quality Monitoring and Process Control – To continuously monitor the reclaimed water being produced and rigorously enforce the approved operating protocol such that only high-quality reclaimed water is delivered to the end users.

Effective Filtration – To optimize performance of the filtration process in order to maximize the effectiveness of the disinfection process in the inactivation of viruses and to effectively remove protozoan pathogens.

Cross-Connection Control – To ensure that effective cross-connection control programs are rigorously enforced in areas served with reclaimed water.

Inspections – To provide thorough, routine inspections of reclaimed water facilities, including facilities located on the property of end users, to ensure that reclaimed water is used in accordance with state and local requirements and that cross-connections do not occur.

Reuse System Management

Water Supply Philosophy – To adopt a "water supply" philosophy oriented towards reliable delivery of a high-quality reclaimed water product to the end users.

Conservation – To recognize that reclaimed water is a valuable water resource, which should be used efficiently and effectively to promote conservation of the resource.

Partnerships – To enter into partnerships with the Department of Environmental Protection, the end users, the public, the drinking water utility, other local and regional agencies, the water management district, and the county health department to follow and promote these practices.

Communications – To provide effective and open communication with the public, end users, the drinking water utility, other local and regional agencies, the Department of Environmental Protection, the water management district, and the county health department.

Contingency Plans – To develop response plans for unanticipated events, such as inclement weather, hurricanes, tornadoes, floods, drought, supply shortfalls, equipment failure, and power disruptions.

Preventative Maintenance – To prepare and implement a plan for preventative maintenance for equipment and facilities to treat wastewater and to store, convey, and distribute reclaimed water.

Continual Improvement – To continually improve all aspects of water reclamation and reuse.

Public Awareness

Public Notification – To provide effective signage advising the public about the use of reclaimed water and to provide effective written notification to end users of reclaimed water about the origin of, the nature of, and proper use of reclaimed water.

Education – To educate the public, children, and other agencies about the need for water conservation and reuse, reuse activities in the state and local area, and environmentally sound wastewater management and water reuse practices.

3.8.2 Examples of Potable Water Separation Standards from the State of Washington

Efforts to control cross-connections invariably increase as part of the implementation of dual distribution systems involving potable and nonpotable lines. A fundamental element of these cross-connection control elements is the maintenance of a separation between potable and nonpotable pipelines. While the specific requirements often vary from state to state, common elements typically include color-coding requirements as well as minimum vertical and horizontal separations. Excerpts from the State of Washington, "Reclaimed Water – Potable Water Separation Standards," are provided below as an example of these requirements.

Policy Requirements: Potable water lines require protection from any nonpotable water supply, including all classes of reclaimed water. For buried pipelines, proper pipe separation must be provided.

General Requirements: Standard potable-nonpotable pipe separation standards should be observed at:

1. Parallel Installations: Minimum horizontal separation of 10 feet (3 meters) pipe-to-pipe.

2. Pipe Crossings: Minimum vertical separation of 18 inches (0.5 meters) pipe-to-pipe, with potable lines crossing above nonpotable.

Special Conditions: Special laying conditions where the required separations cannot be maintained may be addressed as shown in the following examples.

Figure 3-20. A Minimum 5-foot (1.5-meter) Horizontal Pipe Separation Coupled with an 18-inch (46-cm) Vertical Separation

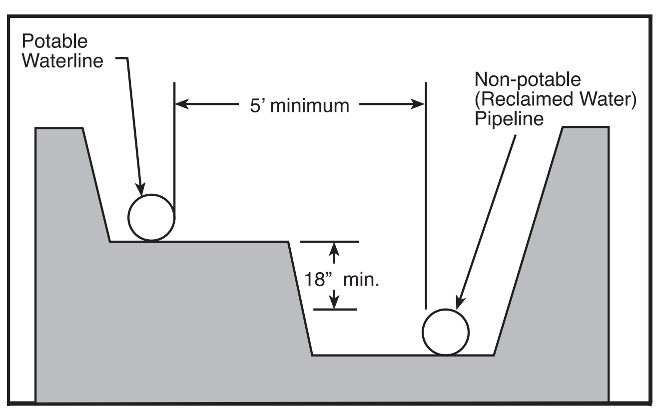
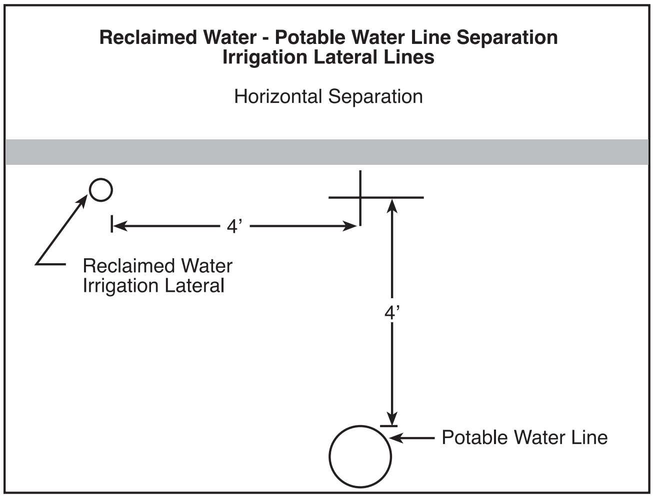


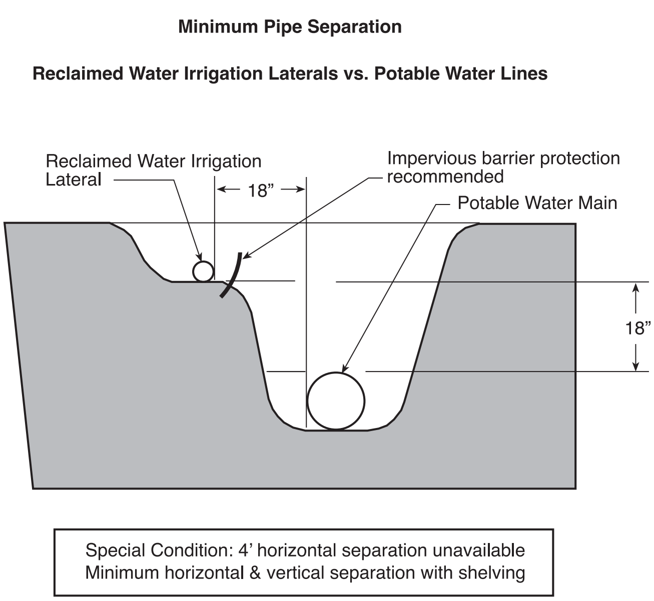
Figure 3-21. Irrigation Lateral Separation



Pipeline Separation: Minimum pipeline separation between any potable water line and reclaimed water irrigation laterals shall be 48 inches (1.2 meters) pipe-to-pipe separation.

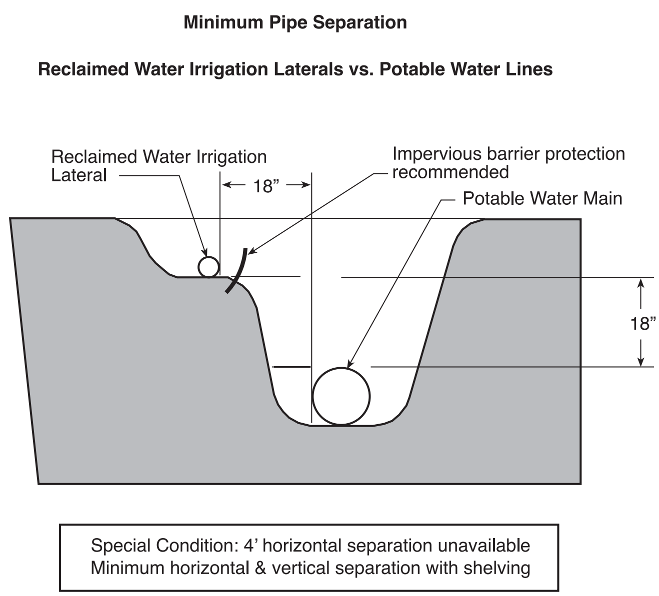
Special Condition Number 1- Irrigation Lateral Crossings: Reclaimed water irrigation laterals will commonly cross above potable water lines due to normal depths of bury. To provide adequate protection, the reclaimed water irrigation lateral shall be cased in pressure-rated pipe to a minimum distance of 4 feet (1.2 meters) on each side of the potable water line.

Figure 3-22. Lateral Crossing Requirements



Special Condition Number 2 - Inadequate Horizontal Separation: Site limitations will likely result in parallel pipe installations with less than 48 inches (1.2 meters) of pipe-to-pipe separation. In these instances, a minimum pipe-to-pipe separation of 18 inches (46 cm) shall be provided, and the reclaimed water irrigation lateral shall be installed a minimum of 18 inches (46 cm) above the potable water pipeline. An impervious barrier, such as PVC sheeting, installed between the irrigation lateral and the waterline for the length of the run is recommended.

Figure 3-23. Parallel Water - Lateral Installation



3.8.3 An Example of Using Risk Assessment to Establish Reclaimed Water Quality

Historically, the microbiological quality of both wastewater effluents and reclaimed water has been based on indicator organisms. This practice has proved to be effective and will likely continue into the foreseeable future.

However, given uncertainties in the use of indicator organisms to control pathogens in reclaimed water and in other waters, regulatory agencies could consider developing a number of guidelines or standards for selected pathogens using microbiological risk assessment. Development of risk-based guidelines or standards could include:

1. Selection of appropriate pathogens

2. Selection of microbial risk models

3. Structuring of exposure scenarios

4. Selection of acceptable risk levels

5. Calculation of the concentration of the pathogen that would result in a risk equal to the acceptable level of risk

As an example, York and Walker-Coleman (York and Walker-Coleman, 1999, 2000) used a risk assessment approach to evaluate guidelines for nonpotable reuse activities. These investigations developed guidelines for *Giardia, Cryptosporidium*, and enteroviruses using the following models:

Organism	Model Used	Parameters
Echovirus 12 (moderately infective)	$P_i = 1 - (1 + N/\beta)^{-\alpha}$ (beta-Poisson)	$\alpha = 0.374$ $\beta = 186.7$
Rotavirus (highly infective)	$P_i = 1 - (1 + N/\beta)^{-\alpha}$ (beta-Poisson)	$\alpha = 0.26$ $\beta = 0.42$
Cryptosporidium	$P_i = 1 - e^{-rN}$ (exponential)	r = 0.00467
Giardia	$P_i = 1 - e^{-rN}$ (exponential)	r = 0.0198

Source: Rose and Carnahan, 1992, Rose *et al.,* 1996

Since specific types of viruses typically are not quantified when assessing viruses in reclaimed water, assumptions about the type of viruses present were required. For the purpose of developing a risk assessment model, it was assumed that all viruses would be highly infective rotaviruses. Helminths were not evaluated, since data from St. Petersburg, Florida showed that helminths were consistently removed in the secondary clarifiers of a water reclamation facility (Rose and Carnahan, 1992, Rose *et al.*, 1996).

In this analysis, an annual risk of infection of 1×10^{-4} was used as the "acceptable level of risk." Two exposure scenarios were evaluated. Average conditions were evaluated based on the assumption that an individual would ingest 1.0 ml of reclaimed water (or its residue) on each of 365 days during the year. In addition, a worst-case scenario involving ingestion of 100 ml of reclaimed water on a single day during the year was evaluated. These exposure scenarios were judged representative of the use of reclaimed water to irrigate a residential lawn. The exposure scenarios could be adjusted to fit other reuse activities, such as irrigation of a golf course, park, or school. The results of this exercise are summarized in **Table 3-16.**

It is important to note that, particularly for the protozoan pathogens, the calculations assume that all pathogens present in reclaimed water are intact, viable, and fully capable of causing infection. A *Giardia* infectivity study conducted by the Los Angeles County Sanitation District (Garcia *et al.*, 2002) demonstrated that *Giardia* cysts passing through a water reclamation facility were not infectious. This basic approach could be applied to other waters and could be used to establish consistency among the various water programs.

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National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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Table 3-16. Average and Maximum Conditions for Exposure

Organism	Units	Calculated Allowable Concentrations	
		Average	Maximum
Giardia	Viable, infectious cysts/100 l	1.4	5
Cryptosporidium	Viable, infectious oocysts/100 l	5.8	22
Enterovirus (a)	PFU/100 l	0.044	0.165

Note: (a) Assumes all viruses are highly infective Rotavirus.
Source: York and Walker-Coleman, 1999, 2000

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